Evaluation of Tank 241-T-111 Level Data and In-Tank Video Inspection

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Abstract: This document summarizes the status of tank T-111 as of April 1, 2013 and estimates a leak rate and post-1994 leak volume for the tank.

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ACRONYMS and ABBREVIATIONS

BBI	Best Basis Inventory
BGS	Below Grade Surface
BTU	British Thermal Unit
cfm	cubic feet per minute
Ci	curie
DST	double-shell tank
FIC	Food Instrument Corporation [gauge]
ft	feet
g	gram
gal	gallon
in.	inches
ILL	interstitial liquid level
IS	interim stabilization
kgal	thousand gallons
LOW	liquid observation well
mL	milliliter
PC-SACS	Personal Computer Surveillance Analysis Computer System
ppm	parts per million
RAS	radionuclide assessment system
RH	relative humidity
SL	surface level
SST	single-shell tank
TWINS	Tank Waste Information Network System
yr	year

1.0 Summary

This report provides an evaluation of the conditions in tank 241-T-111 (T-111) as of April 1, 2013. Tank T-111 was suspected of leaking in 1974 and most of the pumpable liquid was pumped out at that time. The tank was saltwell pumped using a turbine pump in 1976 to 1978. From 1978 to 1993 the tank had an apparent intrusion of over 1.5 inches, which is approximately 700 gal assuming little change to the current central pool size, and sludge porosity, in the tank. In 1993 the liquid level began to decrease and the tank was suspected of leaking again. A jet pump was installed and additional liquid removed to the extent practical in 1994 to1995. From 1995 to 2006 the tank liquid level had a nominal one inch increase before the liquid level began to drop again. The liquid level has been decreasing since 2006 with the decrease rate accelerating with time. After evaluating available data and observing in-tank videos it is concluded that the interstitial liquid level (ILL) drop in this tank is due to the tank leaking.

The level in T-111 stopped decreasing when saltwell turbine pumping was stopped in 1978. When the tank began leaking again after 1994 cannot be determined with certainty, but the leak probably restarted around 2002, with intrusion into the tank masking the leak until 2007. The volume of liquid leaked from the tank from 1995 to April 2013 is estimated to range between 1,000 and 3,900 gal, with the most probable leak volume approximately 2,100 gal. The leak rate as of April 1, 2013 is estimated to range between 2.0 and 3.1 gal/day, with the most probable rate approximately 2.8 gal/day. The conclusion is that the tank is leaking as of April 1, 2013. The leak volume and leak rate values are approximations.

The 2,100 gal leak volume and 2.8 gal/day leak rate as of April 1, 2013 are based upon the scenario described in Section 5.0, which appears the most likely explanation of what has occurred in the tank. The leak volume and leak rate numbers are highly dependent upon assumptions used. Using different assumptions for the rate of intrusion, when the post-1994 intrusion began to decrease, the rate of change for the intrusion, the rate of evaporation from the tank and the waste porosity can all impact the estimated leak volume and leak rate. Alternate scenarios are described in Appendix A.

The history of the tank, current conditions, in-tank video results, and basis for the conclusions are provided. This document is an evaluation of the conditions in tank T-111 as of April 1, 2013; it is not a formal leak assessment prepared in accordance with TFC-ENG-CHEM-D-42, *Tank Leak Assessment Process*. A formal leak assessment was not required since the tank is currently designated as an assumed leaking tank.

2.0 Tank T-111 History to April 2013

Tank T-111 is characterized as an assumed leaker in HNF-EP-0182, *Waste Status Summary for Month Ending December 31, 2012*, Rev 297. This status is based upon a leak from the tank first being noted in 1974, and the leak again becoming evident in 1993.

Tank T-111 is one of twelve 75 ft. diameter tanks in 241-T Tank Farm (T-Farm) constructed between 1943 and 1944 in 200 West Area. The tank has a nominal capacity of 530 kgal. Tank T-111 entered service during the fourth quarter of 1945 with a cascade from Tank T-110 of second cycle decontamination (2C) waste (per RPP-RPT-43169, *2009 Auto TCR for Tank 241-T-111*). The tank was filled with 2C waste, at which time the waste liquid was cascaded to

Tank T-112. Cascading continued until the third quarter of 1946, when tank T-112 was filled. Nearly all of the supernatant of tank T-111 was transferred out and cascading of 2C waste resumed in the first quarter of 1948. When the entire T-110 → T-111 → T-112 cascade became full, waste from the last tank (T-112) was transferred to a crib. This cycle continued until the fourth quarter of 1952. From 1952 to 1956 2C and lanthanum fluoride waste (224) were sent to tank T-111 with the liquid transferred to a crib. The last waste transfer into tank T-111 was in 1956.

The tank contents remained unchanged from 1956 until the second quarter of 1974 when the liquid level began to decrease. The tank was suspected of leaking and most of the supernatant was pumped from tank T-111 in April and May of 1974. The level continued to drop at a decreasing rate from May to October 1974, at which time the waste surface level gauge reading stabilized between 172 and 173 inches until early 1976. Saltwell pumping using a turbine pump began in 1976 and continued periodically until 1978 when pumping was discontinued.

Shortly after pumping was halted the waste level began to rise slowly. The increase continued from 1979 until 1993 at a fairly linear rate indicative of a water intrusion. In 1993 the level began to decrease and it appeared that the tank was leaking again so a saltwell jet pump was installed and operated. Interim stabilization (IS) using the jet pump was complete in 1995.

Following IS pumping the tank T-111 waste level began to rise slowly. The surface level (SL) increase rate was linear from late 1995 until around 2000 to 2002 when the increase rate began to slow. From 2004 until 2006 or 2007 the tank liquid level appeared essentially constant except for normal annual temperature-influenced fluctuations in the waste surface level. The liquid level began to decrease in 2006-2007 and has been decreasing since.

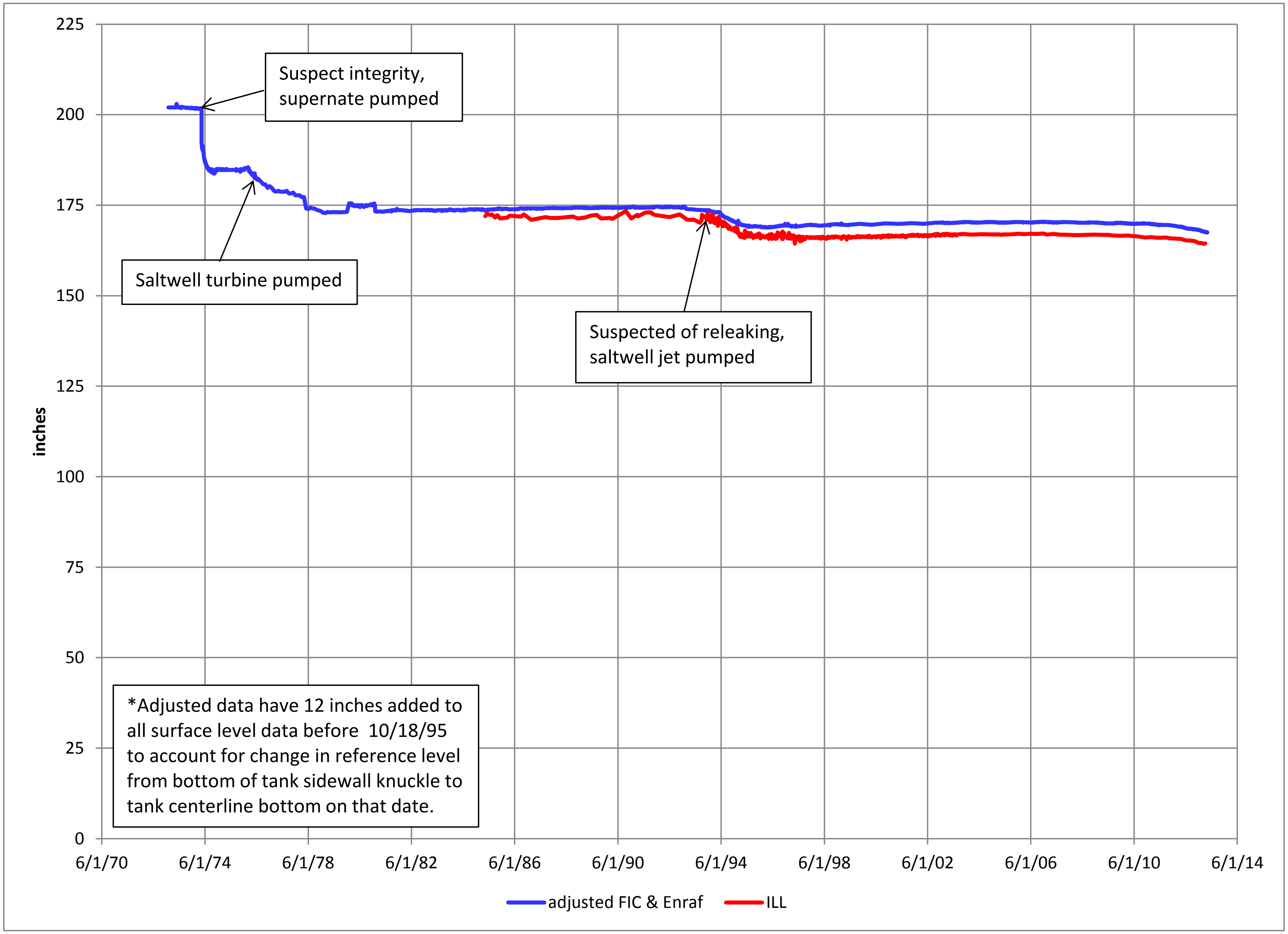
In October 2007 the grading began for the T-Farm surface in preparation for the T-Farm interim barrier that was subsequently installed.

Figure 1 is a plot of the tank T-111 ILL and SL data from 1974 to the present. The data from 1980 were obtained from a Tank Waste Information Network System download on April 2, 2013 (TWINS-1). The pre-1980 SL data were obtained from several sources; daily level data from September 13, 1973 to June 30, 1976 were obtained from old data sheets located in archived information storage boxes (see Reference-Waste Level Data September 13, 1973 to June 30, 1976), monthly data from July 1, 1976 to December 1, 1979 were obtained from various locations (see Reference-Waste Level Data July 1, 1976 to December 1, 1979).

The liquid observation well (LOW), installed in 1985, and the Honeywell Enraf (Enraf) surface level gauge are on opposite sides of the tank from each other but the tank T-111 ILL and SL data track each other closely. This infers the ILL is stabilized throughout the tank waste. From a video taken on February 11, 2013 the Enraf is sitting in a small depression and appears to be reading the ILL.

Most if not all of the SL data from before July 13, 1995 were obtained using a Food Instrument Corporation (FIC) gauge, with some of the 1970s data possibly being obtained with a manual tape. When the Enraf gauge was installed the first reading was only 0.13 inches lower than the last FIC gauge reading. This difference, although insignificant, is addressed in Section 4.0.

Figure 1 Tank T-111 Interstitial Liquid Level and Adjusted* Surface Level Data



The ILL and SL level data for tank T-111 both peaked in late 2006 and have shown decreasing trends since the December 2007 ILL and March 2008 SL, with the negative change rate increasing with time. The significance of this information is that it shows the negative tank evaporation plus leak rate overcame the positive tank intrusion rate sometime in 2007.

The highest ILL reading was in November 2006. The ILL was being measured quarterly, with the highest reading for 2007 obtained in July. No third quarter 2007 ILL reading was recorded and the ILL measurement in December 2007 showed a 0.096 inch decrease from July. The December reading began a progression of decreasing ILLs.

The highest SL reading was in December 2006 when the waste level was at the peak of its periodic annual cycle. The highest reading for 2007 was in September, then the Enraf gauge was out of service until March of 2008. When the Enraf was put back in service the reading was 0.16 inches lower than in September 2007 and the first of a progression of decreasing SLs.

During the summer of 2012 the SL and ILL data trendline slopes for all 149 SSTs were evaluated. It was noted the slopes for tank T-111 had changed from positive to negative in about 2007, with the decrease rates for tank T-111 among the highest of any SST. The LOW monitoring frequency for tank T-111 was increased from quarterly to monthly in September 2012 due to this trend.

The primary leak detection device on tank T-111 is the LOW, per OSD-T-151-00031, *Operating Specifications for Tank Farm Leak Detection and Single-Shell Tank Intrusion Detection*, Rev 1. This is unchanged in OSD-T-151-00031, Rev 2. The operating specification identifies the upper and lower specification change limits for ILL and SL data. The limits are used as flags to automatically highlight data that fall outside of the specification limits when the data are entered into the Personal Computer Surveillance Analysis Computer System (PC-SACS) database. Plots showing the data along with the maximum and minimum specification change limits from OSD-T-151-00031 and a baseline value are available on the PC-SACS database. The tank T-111 ILL reading on November 16, 2012 exceeded the lower baseline limit. A follow-up ILL reading on November 27, 2013 confirmed the below lower specification limit value, and PER 2012-1977 was written on November 27, 2012.

The tank T-111 level decrease rate was observed in the late summer of 2012. A rough evaporation estimate at that time could not account for all the liquid leaving the tank. As a result, the LOW monitoring frequency for the tank was increased and a work package was initiated to obtain an in-tank video. The purpose of the in-tank video was to confirm the tank Enraf gauge was providing valid readings and to determine the fraction of the waste surface which was liquid. The latter is needed to estimate a reasonable assumed tank headspace relative humidity for evaporation calculations and to correlate a level decrease rate to a volumetric decrease rate.

Failure of a tank liner is normally attributed to either corrosion, thermal stresses, or design/construction issues. The tank has never contained thermally hot waste and the tank first leaked about 30 years following the first addition of waste to the tank, so design/construction concerns should have been evident by then. The potential for corrosion of the tank liner significant enough to cause a tank leak is not readily apparent from 1974 tank sample data, but is apparent in 1991. Tank T-111 liquid sample analyses show the liquid in 1974 to have a desirable pH and thus imply a low corrosion rate. The 1974 samples (Internal Memos R. E. Wheeler to R. L. Walser, *Analysis of Tank Farm Samples Sample: T-3304, 111-T*, June 7, 1974 and R. E. Wheeler to R. L. Walser, *Analysis of Tank Farm Samples Sample: T-4893, 111-T*, September 24, 1974, IDMS Accession #1007130273) showed the pH ranging from 12.9 to 13.3 with specific gravities ranging from 1.018 to 1.020. By 1991 the [OH^-] concentration had dropped by a factor of about 1000 and was now in a region where the corrosion rate of the steel liner should increase. Sample results from 1991 (TWINS-2) showed the core sample interstitial liquid pH ranging from 9.8 to 10.2 with the density increased to a range of 1.05 to 1.17 g/mL.

An in-tank video was obtained from tank T-111 on February 11, 2013 with a follow-up video obtained on March 20, 2013. The February 11, 2013 video showed the Enraf plummet to be providing valid data from a small liquid pool, reading the ILL in a small depression under the Enraf riser. The ILL can also be observed in a little depression around the LOW. The central pool around the saltwell screen was estimated at 20 ft. diameter.

The in-tank video provided the information required to complete evaluation of the tank conditions. Following the February 11, 2013 video notification was made by the U. S. Department of Energy that the tank appeared to be leaking. This report describes the tank operations contractor's evaluation of the data and related information, with the conclusion that the tank is leaking.

3.0 Tank T-111 In-Tank Video Inspection Results

Following is a summary of information obtained from the February 11, 2013 and March 20, 2013 tank T-111 in-tank videos. This information provides a description of some of the intrusion related conditions in the tank at this time.

Figure 2 is a composite of tank video screenshots showing most of the tank T-111 waste surface. There is a liquid pool about 20 ft. diameter around the central saltwell screen. Assuming the pool is 6 inches deep the tank T-111 supernatant volume is estimated at about 1,200 gal. The sludge surface is fairly flat with the liquid evident an inch or two below the surface in pools around the LOW and in the tank center. The waste surface appears moist with cracks throughout, similar to the waste appearance in 1994 pre-saltwell pumping photos.

No active intrusion drips were observed during the 2013 videos, but there is considerable evidence of past intrusion into the tank. Figure 3 shows what appear to be white crystalline 'stalactites' that have formed around the tank circumference on the lip of the lead flashing on the top stiffener ring. There are many of these; all appear to have a white drip line in back of them coming from the edge of the lead flashing where it goes into the concrete wall. The 'stalactites' are postulated to be similar to what is formed in caves from liquid dripping and evaporating, leaving the crystalline residue behind. These drip points are seen in some other SST in-tank videos and are evident in 1994 tank T-111 photos, but not so numerous.

Figure 2 Tank T-111 Waste Surface Composite February 11, 2013 and March 20, 2013

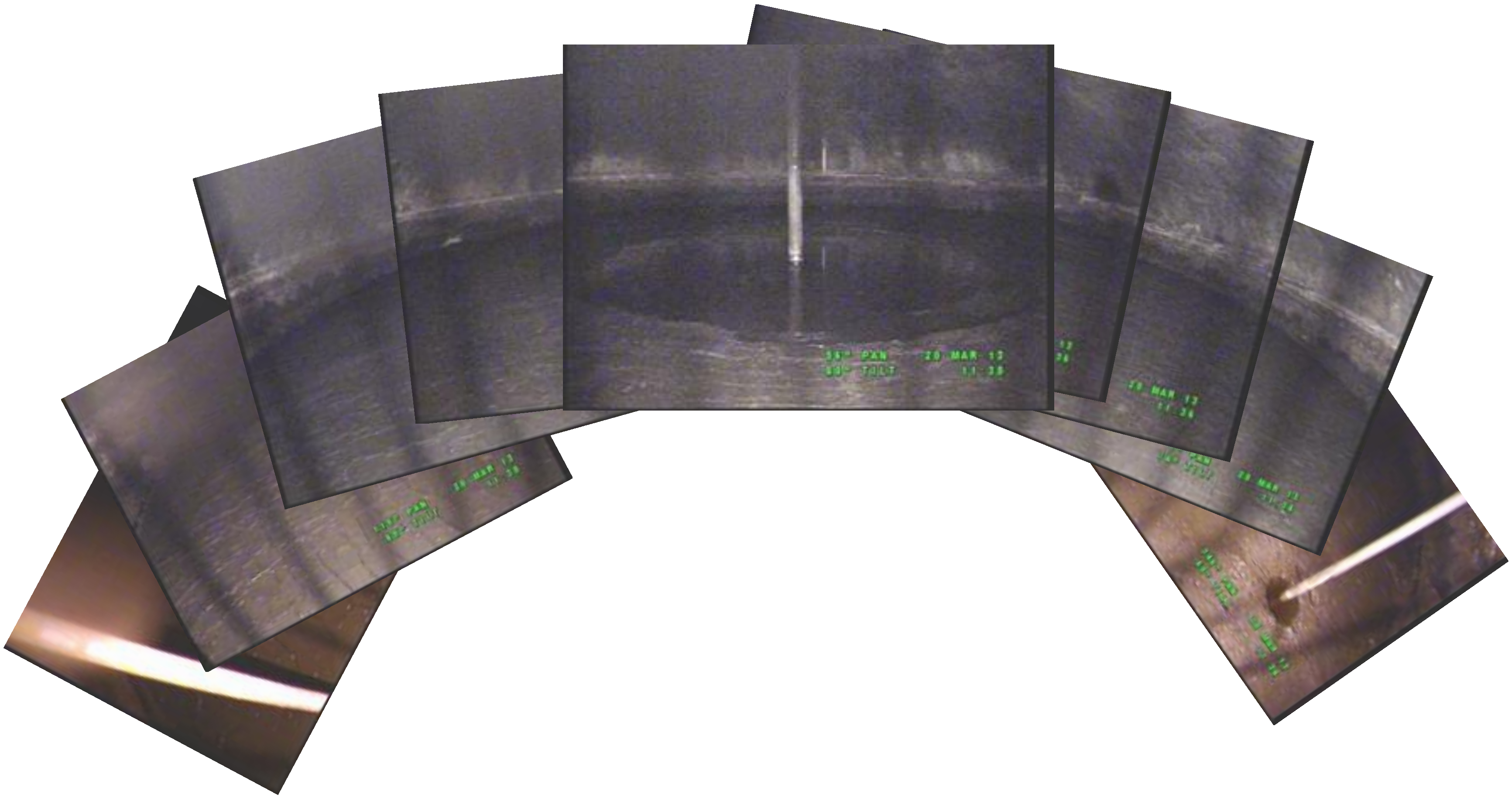


Figure 3 Typical Stalactite on Tank T-111 Top Stiffener Ring Flashing

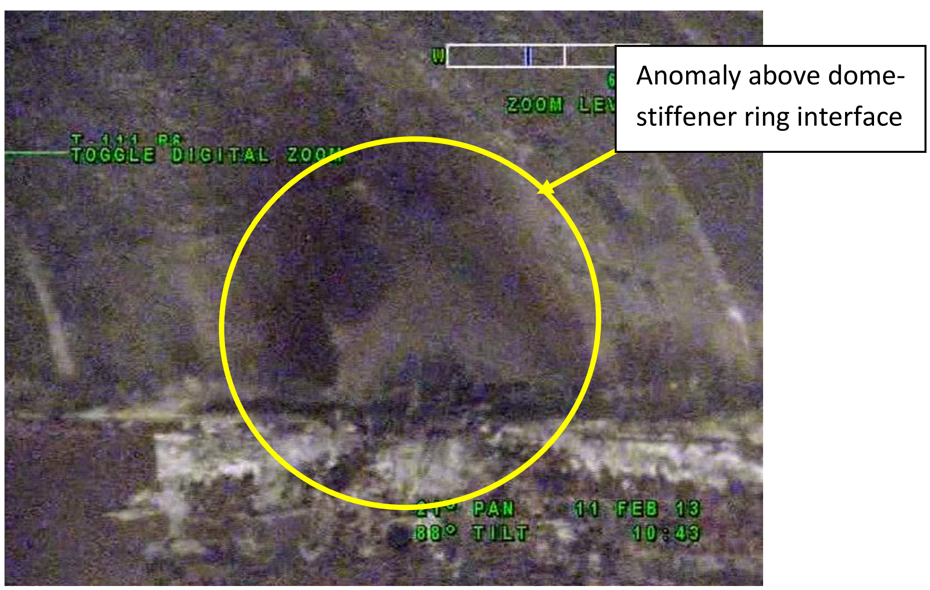
Figure 4 shows a possible intrusion location in the dome. Figure 5 is a screenshot of the waste directly below the Figure 4 location that shows minor depressions which could be from drips from the discolored ceiling area. The video also shows the stain from the Figure 4 location going down the tank dome to the lead flashing above the top stiffener ring.

Figure 4 Possible Past Intrusion Location in Tank T-111 Dome

Figure 5 Moist Depressions Directly Below Dome Stain in Figure 4

Figure 6 is an anomaly located on the southeast area of the dome just above the flashing. The area is black, unlike any other area of the dome. There are black ‘stalactites’ directly underneath the anomaly, and there appears to be a greater accumulation of salts under the anomaly than elsewhere along the lip. At full zoom the camera image is too vague to make out clearly what could have caused the discoloration, but it is possible that this was or is an intrusion location.

Figure 6 Anomaly on SE Area of Tank T-111 Dome Just Above Top Stiffener Ring



4.0 Evaluation of Tank T-111 Liquid Level Data Changes

The change in the level data for any tank is the net impact of all of the following:

- Physical or chemical changes within the waste
- Buildup and release of retained gas within the waste
- ILL not at equilibrium following LOW installation or saltwell pumping (ILL only)
- Plummet resting on uneven solid surface (SL only)
- Recalibration of instrument (SL only)
- Changing of level reference value (SL only)
- Decrease due to porous waste above the ILL (SL only)
- Evaporation from the tank
- Intrusion into the tank
- Leakage from the tank

The potential impact of each of these is considered below.

Physical or Chemical Changes Within The Waste - Physical changes are more likely to occur with saltcake rather than sludge due to the greater potential for chemical changes with time and the potential for the waste to compress due to the higher saltcake porosity. Tank T-111 is all sludge filled with interstitial liquid almost to the waste surface so there is little room for the waste to subside on itself. There is no reason to suspect significant chemical changes continuing to occur within the waste. There are no known physical changes that could be causing the change in SL and ILL data. The last waste was received in the tank in 1956; interim stabilization liquid removal was minimal; and waste temperature changes are minimal. After this much time it is unlikely that the waste is going to begin changing chemically or physically.

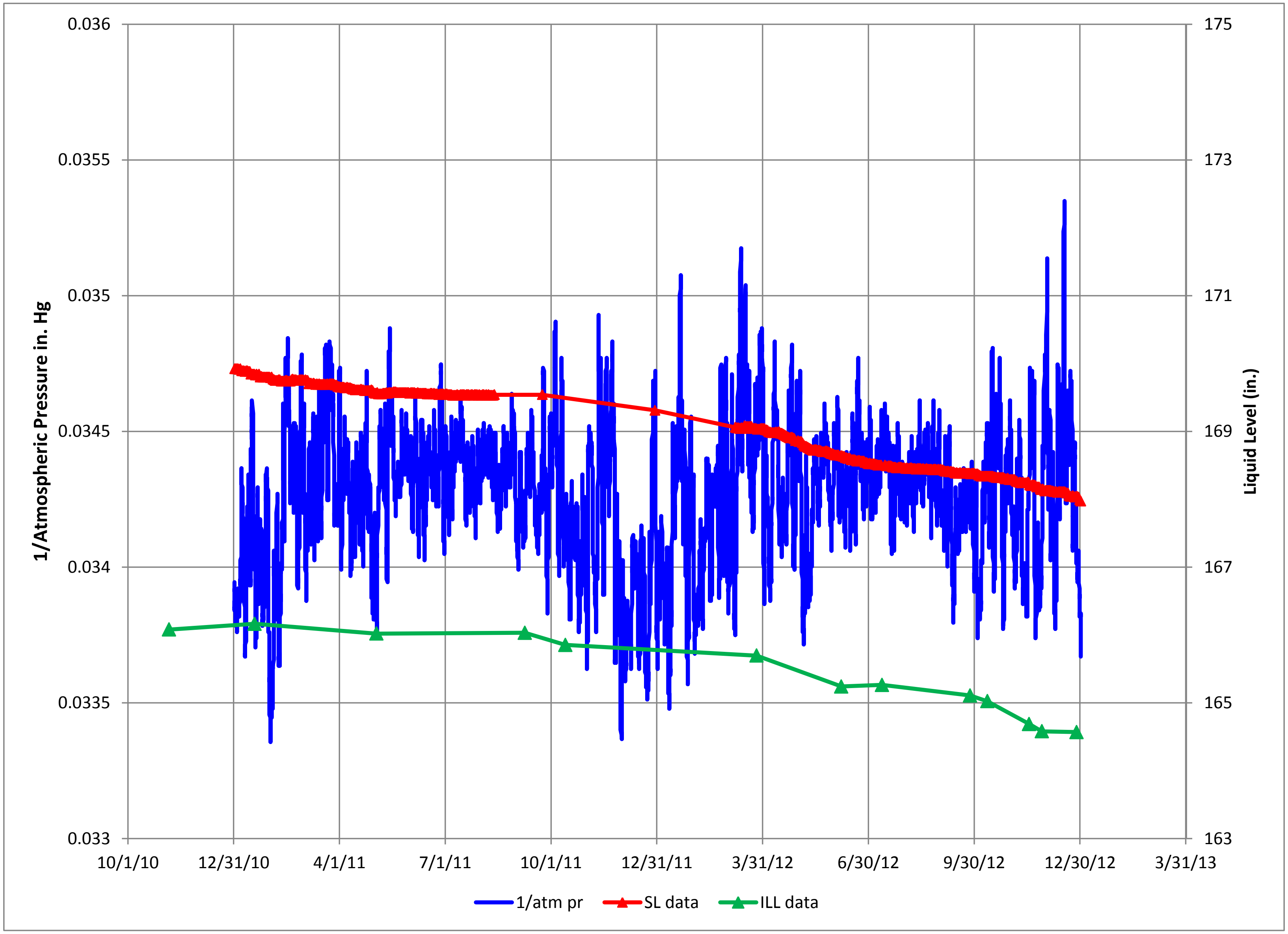
Buildup and Release Of Retained Gas Within The Waste - Buildup and release of gases within the waste has been observed in double-shell tanks (DSTs) as evidenced by a slow increase in the waste level followed by a sudden decrease when the gas is released. Some SSTs may exhibit chronic release of gases at roughly the same rate gases are generated. The potential for gas buildup and release in tank T-111 was evaluated in RPP-RPT-54305, *Initial Assessment for Potential Gas Release Events in Hanford Site Deep Sludge Double-Shell Tank Waste*, 2013, and determined to not be of concern for tank T-111.

Tank T-111 exhibited several very long periods of level increase which appears to have been due to intrusion, but no sudden decreases. The current decrease has been going on since 2008. A flammable gas reading taken from the Enraf gas measurement port on February 11, 2013 showed zero ppm hydrogen and 216 ppm ammonia present (TFC-WO-12-5616, *241-T-111 Perform Video Inspection*).

Figure 7 is an overlaid plot of the tank T-111 level data and the reciprocal of the atmospheric pressure for 2011 - 2012. There is no correlation between the level data and atmospheric pressure, further showing there is no significant flammable gas presence in the tank.

The level change in tank T-111 is not due to gas buildup and release.

Figure 7 2011 – 2012 Reciprocal of Hanford Atmospheric Pressure and Tank T-111 Liquid Level Data



<u>ILL Not at Equilibrium following LOW Installation or Saltwell Pumping</u> - The LOW in tank T-111 was installed in 1985 and the ILL has roughly tracked the surface level monitoring device since shortly after LOW installation. The ILL has gone up and down with the saltwell pumping in 1994 to 1995 and the apparent intrusions before and after the 1994 to 1995 saltwell pumping. The LOW and Enraf gauge are on opposite sides of the tank (65 to 70 ft apart) and track each other closely. The ILL is just below the waste surface and is definitely at equilibrium, i.e., it is not stabilizing because the ILL is at a different height in parts of the tank.

<u>Enraf Plummet Not Resting Correctly</u> - The in-tank video taken on February 11, 2013 shows the plummet is resting in a small depression and is not hung up on any waste surface that would skew the level data trend. The plummet normally registers the waste surface in a tank or the surface at the bottom of a depression, in tank T-111 it appears to be measuring the interstitial liquid level that is only a few inches below waste surface. For tank T-111 the plummet is giving consistent trend data that are believed to reflect the interstitial liquid level in the tank.

<u>Recalibration of Level Gauge</u> - Most if not all of the T-111 surface level data up to July 13, 1995 were obtained with an FIC gauge. It is possible that some of the data in the early to mid-1970s was obtained with a manual tape. When the switch from an FIC gauge to an Enraf was made on July 13, 1995 the first Enraf reading was only 0.13 inches different than the FIC reading. This change is far less than the step change usually seen with a gauge type change, and is inconsequential to the surface level data trend information used in this document.

Enraf calibration records were reviewed for the 2007 to 2013 time period. The gauge was recalibrated in 2007, 2009, and 2011. The tank T-111 Enraf calibration on September 4, 2007 had As Found and As Left gauge output readings of 170.33 and 170.36 inches (CLO-WO-1250, Work Package *241-T, 111* [sic] *Enraf Inspection*, September 4, 2007). The tank T-111 Enraf calibration on September 10, 2009 had As Found and As Left gauge output readings of 169.99 and 170.1 inches (TFC-WO-09-1853, Work Package *241-T, 111* [sic] *Enraf Inspection*, September 10, 2009). The tank T-111 Enraf calibration on December 30, 2011 had As Found and As Left gauge output readings of 169.38 and 169.31 inches (TFC-WO-11-3306, Work Package *241-T, 111* [sic] *Enraf Inspection*, December 30, 2011). The differences between the As Found and As Left values have negligible impact on the level data trend lines slopes.

<u>Change of Tank Level Reference</u> - The change from using the bottom of the tank knuckle to using the tank centerline bottom as the reference point for tank T-111 level gauge data was made on September 18, 1995. This change is reflected in the tank T-111 data plots by the addition of 12 inches (the elevation difference between the bottom of the tank knuckle and the tank centerline bottom) to all waste surface level data from before September 18, 1995 used in this document. No change is necessary for the ILL data since these values were already referenced to the bottom centerline of the tank.

<u>Waste Subsiding Due to Porosity Above the ILL</u> - With waste subsiding into porous openings between waste solids the ILL would be expected to increase or remain constant, but for tank T-111 the decrease in ILL data mirrors the decrease in SL data. The ILL in tank T-111 is only a few inches below the waste surface so there is negligible room for the waste surface to drop onto porous openings between the solids.

<u>Evaporation</u> - The following provides an estimate of the maximum and most likely volumes of liquid that can reasonably be expected to be removed from tank T-111 via evaporation.

All SSTs with a liquid surface or with the ILL near the waste surface will lose some liquid due to evaporation if the tank can vent to the atmosphere. The volume of liquid lost is dependent upon the tank breathing rate, the incoming ambient air humidity and temperature, and the tank headspace air temperature and humidity.

Breathing rates of selected SSTs were measured and documented in PNNL-11683, *Measurements of Waste Tank Passive Ventilation Rates Using Tracer Gases*, 1997, and PNNL-11925, *Waste Tank Ventilation Rates Measured with a Tracer Gas Method*, 1998. Most of the tank breathing rates, excluding those for tanks known or suspected of having an intertie to a ventilated tank, were in the range of 2 to 5 cfm. A preliminary tank T-111 breathing rate has been estimated at about 2.4 cfm. A final value for the tank T-111 breathing rate and the basis for it will be derived in RPP-RPT-54981, *Initial Evaluation of Tanks with Decreasing Baselines Selected for Review in Letter WRPS-1301005*, which will review tank level decreases in all twenty SSTs listed in WRPS-1301005. The 2.4 cfm is on the low end of the 2 to 5 cfm range for breathing rates measured in PNNL-11683 and PNNL-11925, which means the estimated tank leak rate provided in this document is conservative.

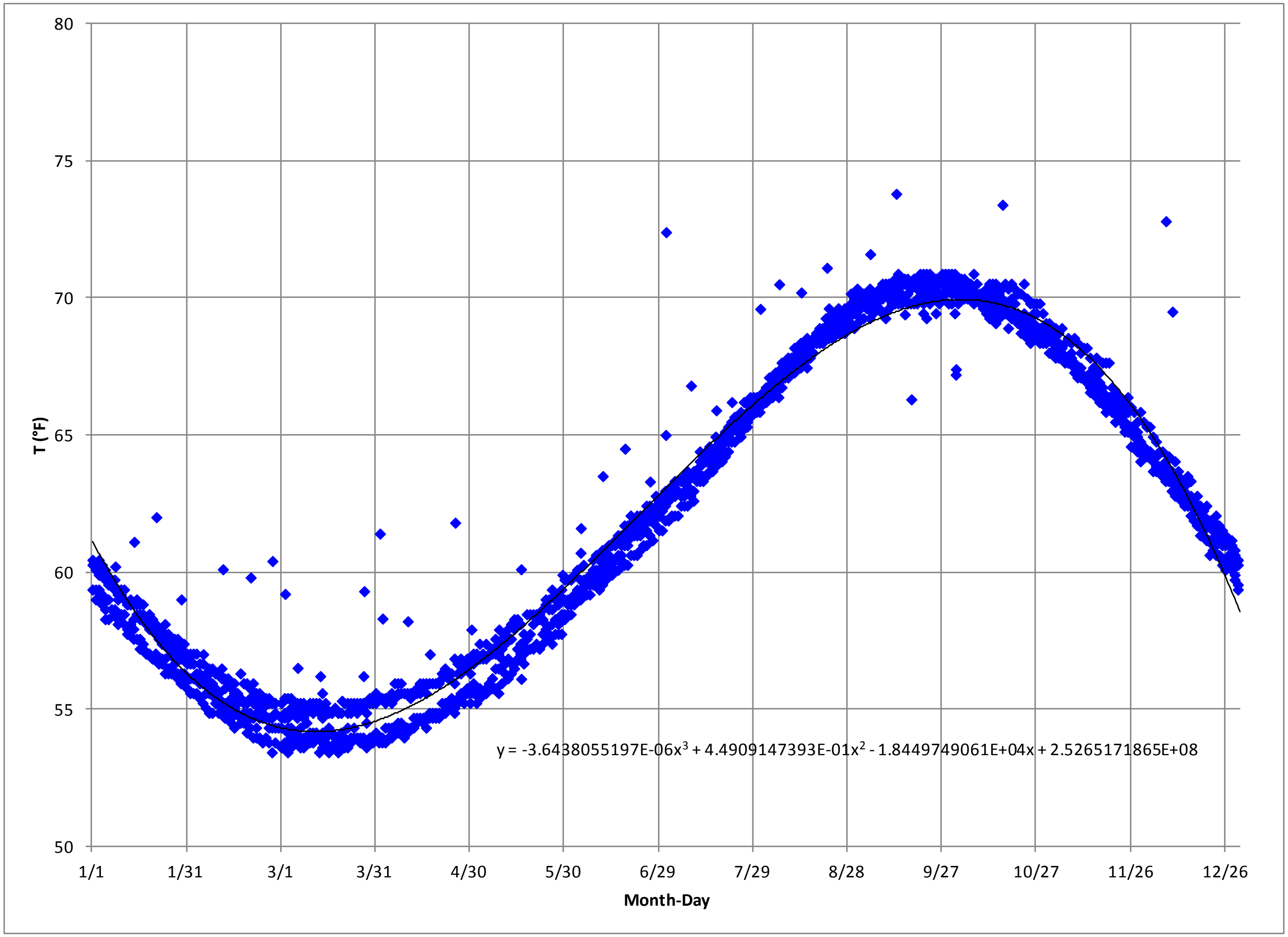
For the purpose of estimating an upper bound for a tank T-111 evaporation rate a tank breathing rate of 6 cfm is assumed. This is the value recommended for a tank T-111 breathing rate in RPP-5660, *Collection and Analysis of Selected Tank Headspace Parameter Data*, 2000.

Tank T-111 headspace temperature data going back to 2002 were downloaded from the TWINS database (TWINS-2) as an Excel file. The highest thermocouple, #11, was selected as the headspace temperature assumed representative of the air leaving the tank. The tank T-111 waste and headspace temperatures cycle annually with the seasons. Because there is negligible heat generation within the tank T-111 waste (see Table 1 below) the year date was ignored for the temperature data and the temperatures plotted against just the month and the day in order to obtain an estimate of the daily average headspace temperature. Figure 8 shows the 2002 to 2012 tank T-111 headspace temperature data. Excel was used to provide a best fit polynomial trend line, and the trend line formula then used to calculate a tank T-111 headspace temperature for any day of the year.

Hourly ambient temperature, pressure, and relative humidity data for January 1, 2010 through December 31, 2012 were obtained from Hanford Meteorological Station personnel and downloaded into an Excel file.

An Excel file was built using the ambient data, a calculated tank T-111 headspace temperature, an assumed relative humidity (RH) in the tank T-111 headspace air, and an assumed tank breathing rate that calculated the water content in the air leaving the tank and in the air entering the tank on an hourly basis for the three years from 2010 to 2012. Using a 2.4 cfm breathing rate and assuming the tank headspace RH is 85% (per HNF-3588, *Organic Complexant Topical Report*, Rev 1, 2003) the RH was measured in 1995 at 85.9% under tank waste surface conditions essentially the same as at present) the annual tank T-111 evaporation rate was estimated at 63 gal/yr. Using a conservative 95% RH and a 6 cfm breathing rate resulted in an estimated upper bound to the tank T-111 evaporation volume of 193 gal/yr.

Figure 8 Tank T-111 Headspace Temperature Annual Cycle



For contrast, three other tanks in T-Farm with known liquid surfaces (T-102, T-103, T-112) show level decreases (assumed to be evaporation) in the 11 to 25 gal/yr range, but these three tanks have much lower waste levels of 17 to 32 inches as opposed to the 168 inches in tank T-111. With the higher waste level in tank T-111 it is assumed the evaporation rate could be higher because of the reduced distance to tank vapor exit points (primarily breather filter and pit drains).

Using the nominal evaporation rate of 6 gal per day per 100 cfm from a tank with a liquid or wet surface given in RPP-40545, *Quantitative Assumptions for Single-Shell Tank Waste Retrieval Planning*, Rev 2, a 2.4 cfm tank T-111 breathing rate gives an evaporation rate of 53 gal/yr.

The tank headspace air temperature is largely dependent upon the waste heat generation rate. The Best Basis Inventory (BBI) lists 46 radionuclides in the tank T-111 waste. Of these, only nine contribute greater than 0.01% of the heat generation rate. Table 1 lists these radionuclides along with a calculated heat generation rate.

Table 1 Radionuclides Contributing Greater Than 0.01% to the Tank T-111 Waste Heat Generation Rate

Radionuclide	Ci[1]	Heat Generation Rate (watts/Ci)[2]	Heat Generation Rate (watts)
90Sr	7.77E+03	6.70E-03	5.20E+01
90Y	7.77E+03	0.00E+00 (with parent)	0.00E+00
99Tc	1.66E+01	5.99E-04	9.94E-03
137Cs	1.95E+02	4.82E-03	9.39E-01
137mBa	1.84E+02	0.00E+00 (with parent)	0.00E+00
234U	2.42E+00	2.88E-02	6.97E-02
238Pu	1.23E+00	3.32E-02	4.08E-02
238U	2.47E+00	2.53E-02	6.25E-02
239Pu	2.61E+02	3.11E-02	8.11E+00
240Pu	3.02E+01	3.12E-02	9.41E-01
241Am	9.82E+01	3.34E-02	3.28E+00
Sum			65.5 (223 BTU/hr)

[1] From TWINS-3 download, decay date January 1, 2008
[2] From HNF-EP-0063, *Hanford Site Solid Waste Acceptance Criteria*, Rev 14 (reissue), August 11, 2008

The 223 BTU/hr radiolytic heat generation rate for the tank is very low, and has little effect on the volume of water evaporated since most of this heat is lost to the surrounding soil. Although a 63 to 193 gal/yr evaporation rate will only require ~58 to 178 BTU/hr of heat input, the heat to evaporate the water in tank T-111 comes primarily from the incoming air and the top few inches of the tank waste.

For the purpose of this document it is assumed that tank T-111 has a minimum evaporation rate of zero gal/yr, a best estimate of 63 gal/yr, and a bounding maximum rate of 193 gal/yr.

Intrusion and Leakage - Tank SL and ILL data plots show the net impact of all the preceding factors, plus intrusion and leakage. A leak rate for tank T-111 is estimated by calculating the net liquid volume change rate and then subtracting the impacts of all other factors.

Figure 1 indicates tank T-111 experienced an intrusion from at least 1979 to about 2007, with the apparent leaking and subsequent pumping in 1993-1995 masking any intrusion during that period. Whether the intrusion is still occurring in tank T-111 since 2007 is open to question. No visible drips were observed during the in-tank videos taken on February 11, 2013 and March 20, 2013, but there was evidence of past intrusions. The change in slope direction for the tank T-111 SL and ILL data plots began around the time surface grading began in T-Farm in October 2007 in preparation for the T-Farm surface barrier. However, a decrease in the level change increase rate is evident beginning in early 2002, long before the grading began. Whether the intrusion rate decreased before grading began, after grading, or remained the same impacts the calculated leak rate.

Estimated tank T-111 leak rates and a post-1994 tank T-111 leak volume are derived by:

1. Estimating SL and ILL in./yr change rates for time periods from 1979 on, excluding active pumping periods or when the ILL had not yet stabilized
2. Plotting SL and ILL in./yr change rates vs. time
3. Deriving a post-1994 tank liquid level in./yr change rate plot and formula
4. Correlating the liquid level in./yr change rate to a volumetric gal/yr change rate
5. Estimating a volumetric intrusion rate
6. Estimating a volumetric leak rate from:

   $$Net\ Change\ Rate = Intrusion\ Rate - Evaporation\ Rate - Leak\ Rate$$

   rearranging,

   $$Leak\ Rate = Intrusion\ Rate - Evaporation\ Rate - Net\ Change\ Rate$$

7. Estimating a leak volume from the volumetric leak rate and the time

Leak rate estimates are provided in Appendix A for a number of scenarios to give an estimated range for the tank T-111 leak rate and a tank T-111 leak volume (post-1994 only).

Surface Level and Interstitial Liquid Level Change Rates – The data for Figure 1 were divided up into the following time periods for calculation of liquid level change rates:

1. Period SL 79-89: surface level from March 1, 1979 to January 3, 1989, assumed linear change rate. The spurious 1.75 in. data spike during the period was omitted.
2. Period SL 89-92: surface level from January 3, 1989 to January 2, 1992, assumed linear change rate.
3. Period SL 92: surface level from February 26, 1992 to June 28, 1992, assumed zero change rate.
4. Period SL 92-94: surface level from July 16, 1992 to May 15, 1994, with questionable data from November 23, 1992 to January 4, 1993 omitted, assumed polynomial change rate.

5. Period undesignated, May 15, 1994 to July 13, 1995: saltwell jet pumping and SL equilibration.
6. Period SL 95-99: surface level from July 13, 1995 to May 10, 1999, assumed linear change rate.
7. Period SL 99-13: surface level from May 10, 1999 to April 1, 2013, assumed polynomial change rate.
8. Period ILL 85-92: interstitial liquid level from April 12, 1985 to October 22, 1992, assumed linear change rate.
9. Period ILL 92-94: interstitial liquid level from October 22, 1992 to May 12, 1994 (last ILL data point before start of saltwell jet pumping), assumed linear change rate.
10. Period undesignated, May 19, 1994 to May 14, 1998: saltwell jet pumping and ILL equilibration.
11. Period ILL 98-03: interstitial liquid level from May 14, 1998 to January 30, 2003, assumed linear change rate.
12. Period ILL 03-13: interstitial liquid level from February 5, 2003 to March 4, 2013, assumed polynomial change rate.

Figure 9 shows the SL and ILL data with the separate regions identified. The time periods were selected based upon engineering judgment to enable linear change rates to be applied to the extent practical.

Excel was used to calculate the regression equation for the trendline in each period. The first derivative was then calculated for each period formula to give the SL or ILL change rate at any point on the trendline.

Plotting SL and ILL Change Rates vs. Time - The resulting change rates calculated for each of the time periods are plotted in Figure 10.

The change rate data through 1995 are not used further in this document except to show the surface level intrusion rate up to about 1993 was similar to or less than the intrusion rate up to about 2003.

Deriving a Post-1994 Tank T-111 Liquid Level Change Rate and Formula - For most tanks the SL and ILL data do not track each other because they measure different surfaces. Tank T-111 is different because the level gauge providing the surface level data is measuring the ILL. The video taken on February 11, 2013 shows the Enraf plummet in a small depression measuring the liquid level. The LOW and Enraf are on opposite sides of the tank but the ILL and SL data for tank T-111 track each other closely, as do the calculated change rate data given in Figure 10. The calculated SL and ILL change rate data for tank T-111 were therefore averaged for each day from July 13, 1995 to April 1, 2013 with the resulting values plotted in Figure 11. A regression line through the Figure 11 data points was calculated in Excel to provide a formula for the tank T-111 level change rate between July 13, 1995 and April 1, 2013. Based upon Figure 11, the tank T-111 liquid level change rate reduced to zero around the beginning of 2006.

Correlating The Liquid Level Change Rate with A Volumetric Change Rate - The change rate plot in Figure 11 gives a change rate in in./yr for the tank T-111 liquid level. Correlating this to a volumetric change rate, e.g., gal/yr requires estimation of the fraction of the waste surface that is liquid and the waste porosity.

Figure 9 Periods Used for Estimation of Tank T-111 Surface Level and Interstitial Liquid Level Data Change Rates

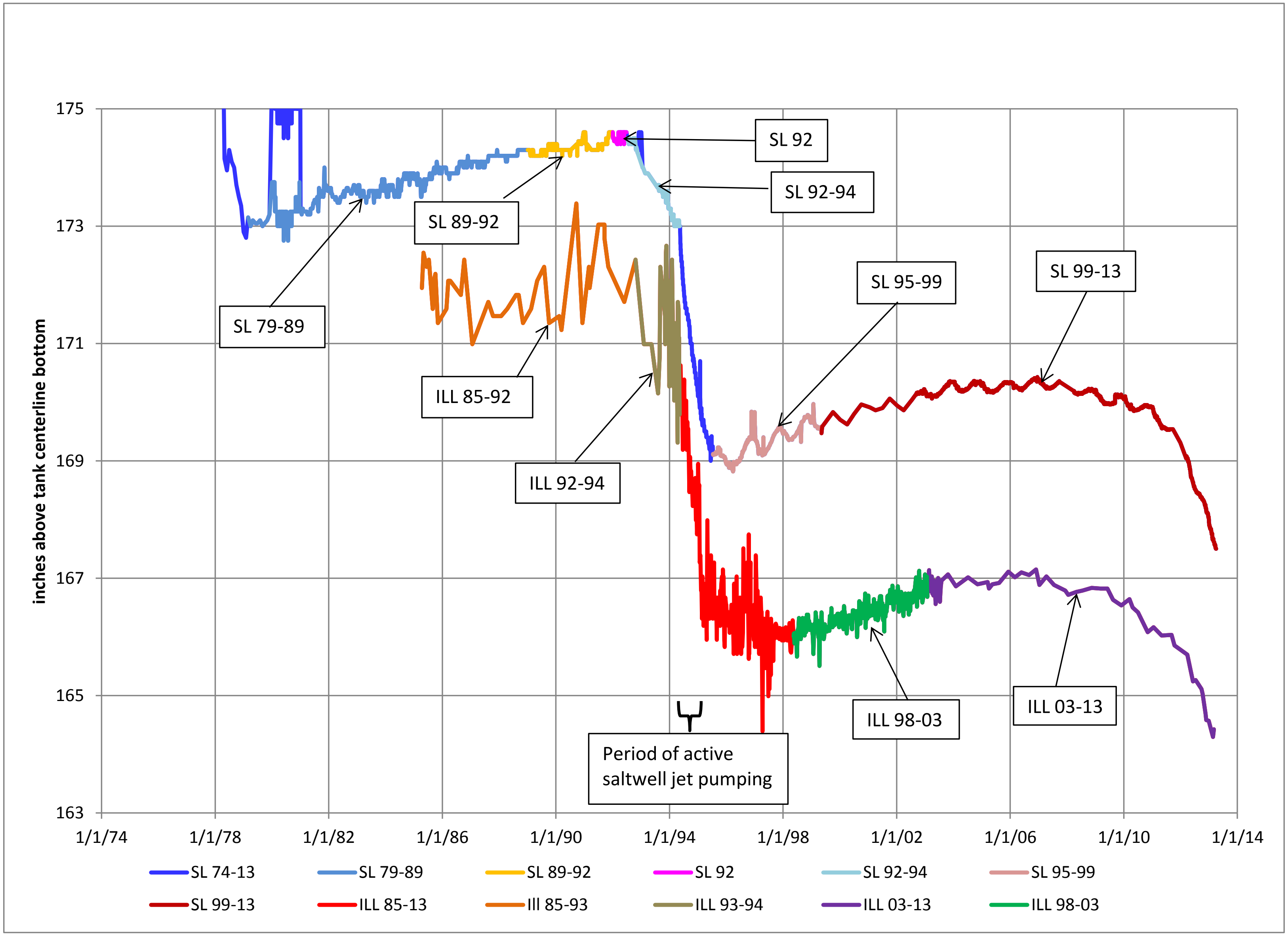


Figure 10 Tank T-111 Surface Level and Interstitial Liquid Level Data Change Rates

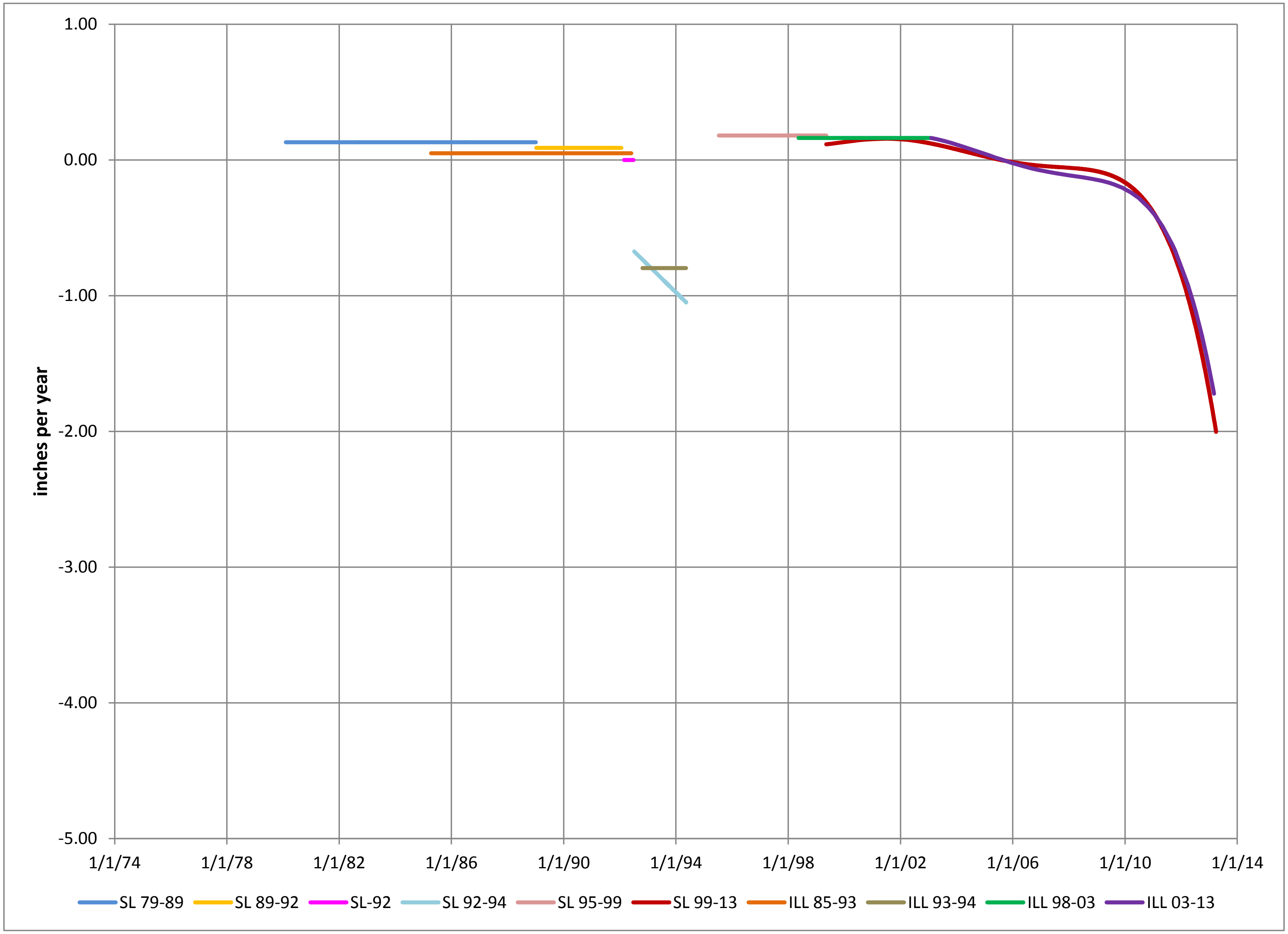


Figure 11 Tank T-111 Average Liquid Level Change Rate

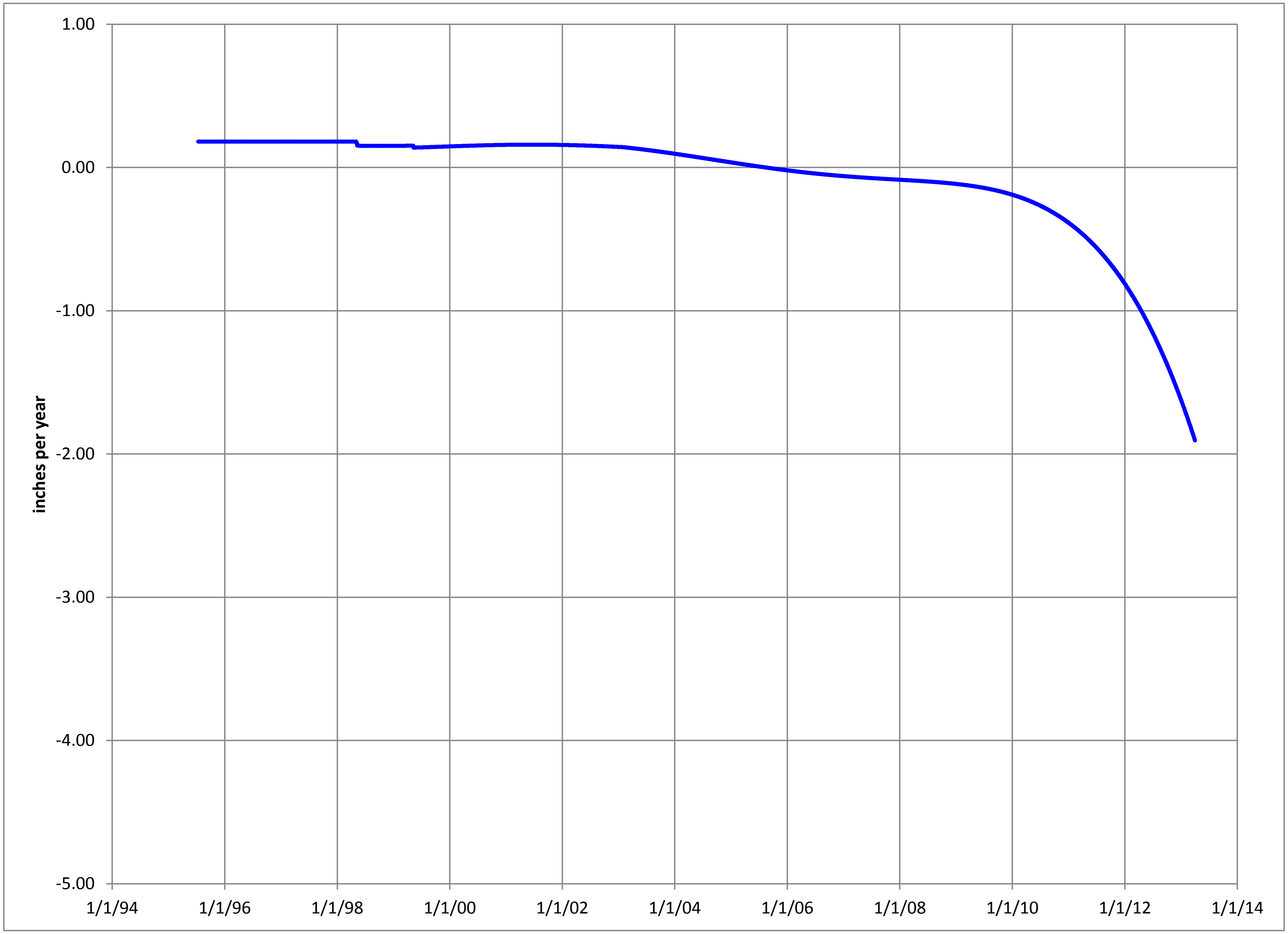


Figure 12 is a sketch of the tank T-111 cross-section. In the center of the tank is a pool estimated at about 20 ft. diameter (see Figure 2). The pool depth is unknown but appears to be 6 inches or more from the video, so a change in liquid level up or down of a few inches should not significantly change the diameter of the pool. The liquid level within the waste is within a few inches of the waste surface. For a liquid level change of height ΔL, the volumetric change rate is equal to the level change multiplied by a conversion factor for volume per unit depth and the change in liquid volume in the central pool plus the change in liquid volume in the waste, with the result divided by the change measurement time. Conservatively ignoring capillary action (which will retain liquid in the waste) the volumetric change rate is:

$$Volumetric\ Change\ Rate\ gal/yr = \ \Delta L\ in./yr \quad 2750\ gal/in.\ \ [f_{ls} + (\ 1 - f_{ls}]\theta)$$

where:

2750 gal/in. is the number of gallons of waste per inch of height in a 75 ft. diameter tank
f_{ls} = fraction of the waste surface that is liquid
θ = waste porosity

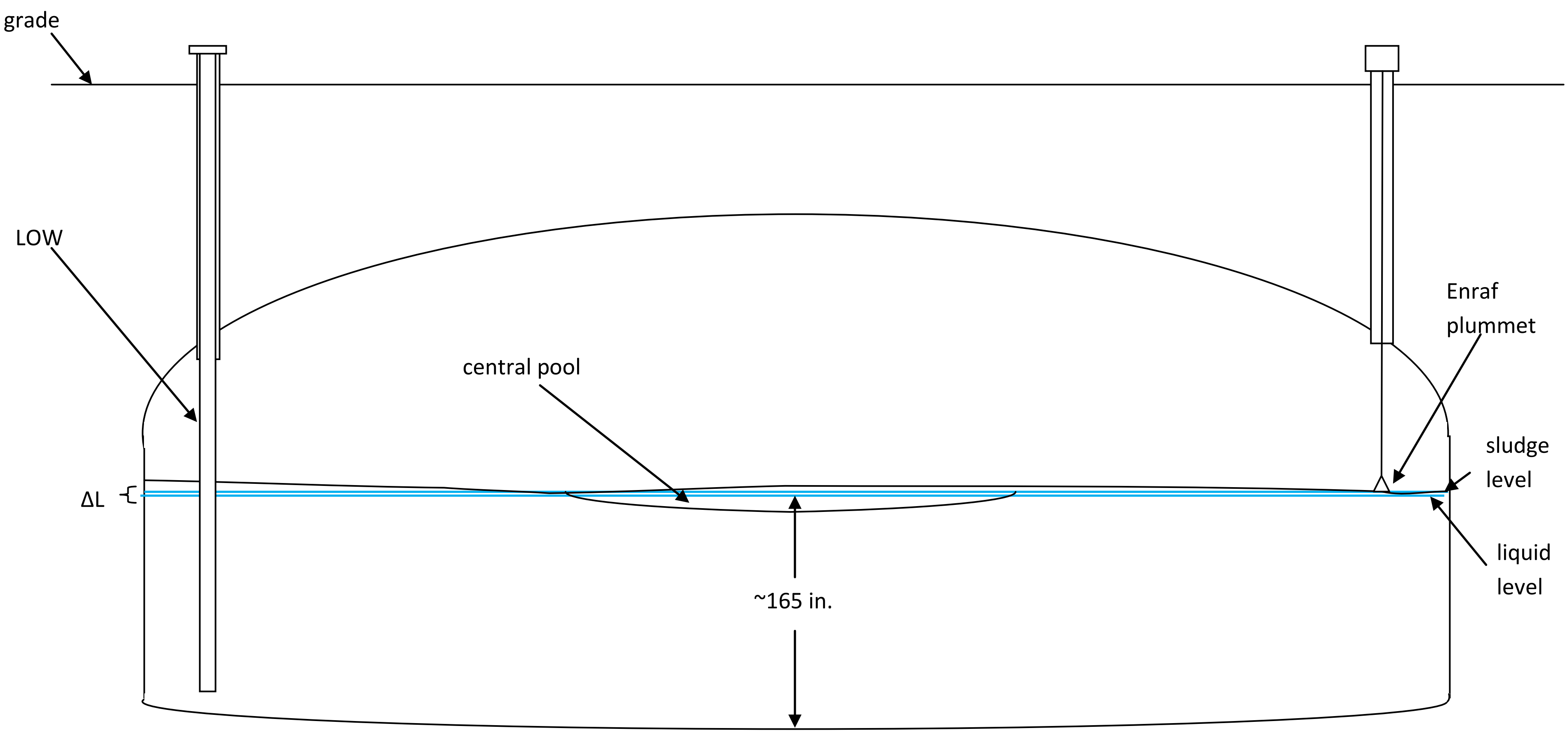
The fraction of the waste surface that is liquid, for a 20 ft. diameter pool, is $20^2 \div 75^2 = 0.071$. This was rounded up to 0.08 for conservatism.

The waste porosity for tank T-111 is unknown, but values used in the past for estimating interim stabilization drainable liquid content for sludge in other SSTs have ranged from 0.05 to 0.17. Most values used for past calculations were around 0.12. The saltwell pumping information for tank T-111 in HNF-SD-RE-TI-178, *Single-Shell Tank Interim Stabilization Record*, Rev 9A, 2007, indicates a porosity of 0.105 based upon dip tube measurements. Based upon the difficulty of saltwell pumping in tank T-111 in both the 1970s and 1990s it is apparent that the tank T-111 waste has a low porosity. For the purposes of these calculations it is assumed that tank T-111 waste has a porosity of 0.105, the same as measured at the end of interim stabilization in 1995 and given in HNF-SD-RE-TI-178, Rev 9A. The tank T-111 drainable interstitial liquid volume of 38 kgal in HNF-EP-0182, Rev 297, is based on the same assumed porosity of 0.105.

Therefore, the volumetric change rate for tank T-111 is assumed to be:

$$Volumetric\ Change\ Rate\ \ \frac{gal}{yr}$$
$$= \ \Delta L\ in./yr\ \ \times\ \ 2750\frac{gal}{in.}\ \ \times\ \ 0.08 + \quad 1 - 0.08\ \ \times 0.105 \quad = 486\Delta L$$

Figure 12 Cross-Section Sketch of Tank T-111 and Waste



Estimating a Volumetric Intrusion Rate – When all other impacts are accounted for the net change rate for a tank is:

$$Net\ Change\ Rate = Intrusion\ Rate - Evaporation\ Rate - Leak\ Rate$$

This equation assumes the leak rate and evaporation rate are stated as positive values.

Rearranging:

$$Intrusion\ Rate = Net\ Change\ Rate + Evaporation\ Rate + Leak\ Rate$$

It is impossible to know the intrusion rate into a tank without knowing the evaporation rate and the leak rate. In the above formula there are two unknowns (leak rate and intrusion), one known (net change rate from Figure 11), and one estimated value (evaporation). What will be done to estimate a T-111 intrusion rate for this document is:

- Use the time period from 1995 to 2002 when the net change rate was constant and assume the intrusion rate, evaporation rate, and leak rate were constant for this period.
- Estimate the 1995 to 2002 intrusion rate for minimum and maximum bounding tank T-111 leak rates for the same period.

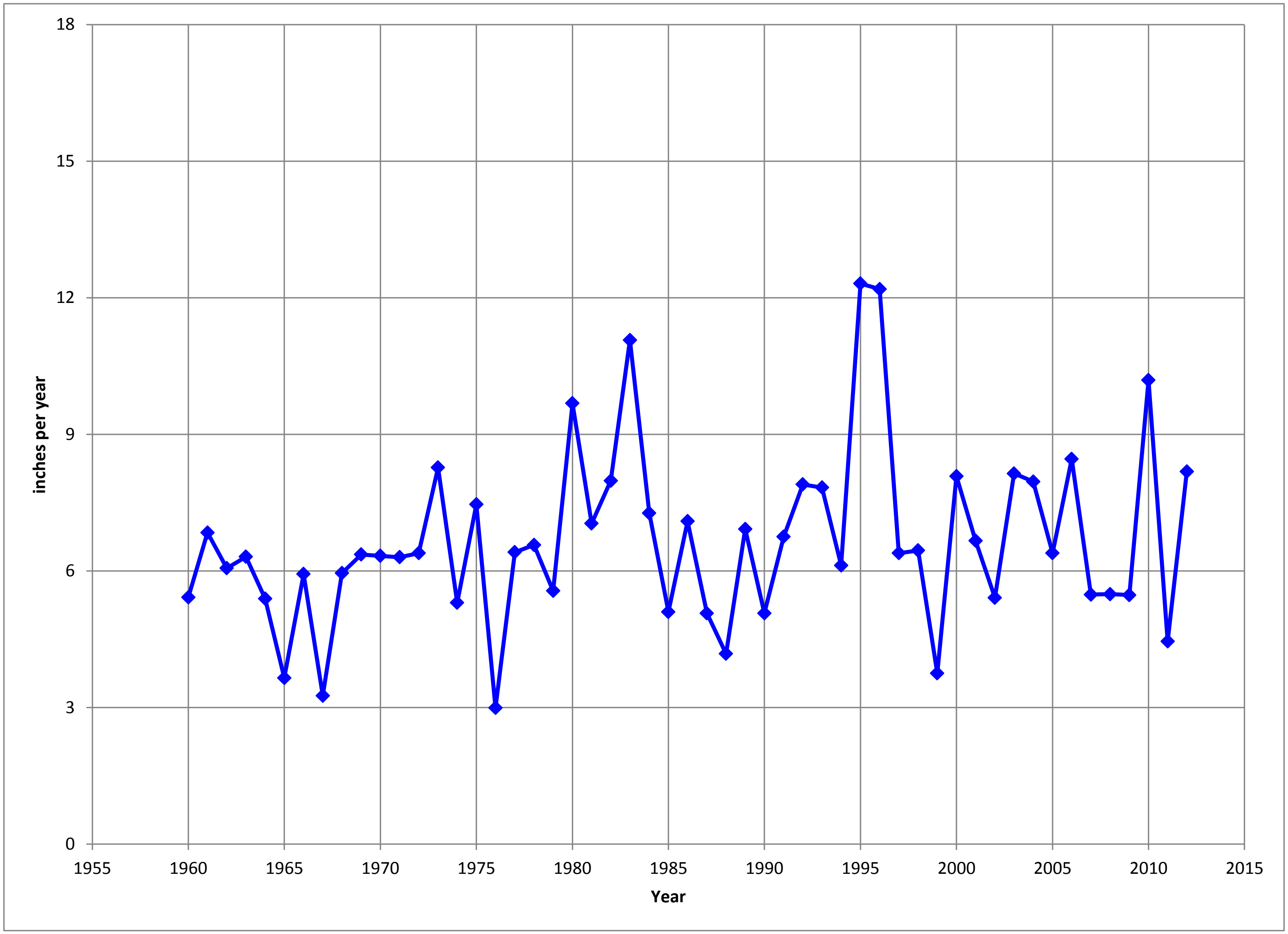
Figure 13 is a plot of the annual precipitation data from the Hanford Meteorological Station since 1960. There has been no significant change in the annual precipitation rate that would have caused a general decrease in the tank T-111 intrusion rate. A trendline (not shown) through the data points shows a very slight annual increase in precipitation. There were spikes in the precipitation in 1980 to 1983 and 1995 to 1996 which may have contributed to the intrusions from 1979 to 1992 and 1995 to 2006, but there are no significant precipitation data trends that mirror the level plots.

With no significant change to the precipitation rate it is reasonable to assume the intrusion rate into a tank will be relatively constant on an annual basis unless something is done to alter the precipitation flow into the soil above the tank or into lines/risers/pits with connections to the tank.

No changes to the environs around tank T-111 have been identified that would have altered the intrusion rate between 1995 and when the T-Farm grading began in October 2007. Therefore, it is reasonable to assume the intrusion rate into tank T-111 was constant at least up to 2002.

The 1995 to 2002 time period is a good period to select for estimation of the intrusion rate because the leak rate was likely zero during that time. Considering the combined effects of corrosion/erosion at a leak location, changing tank liquid level, and sludge pluggage at the leak location gives a high probability of any leak rate (other than zero) being non-linear over an extended period of time. This document includes as an alternate scenario a maximum leak rate occurring from 1995 to 2002, to give an upper limit to a tank T-111 leak volume.

Figure 13 Hanford Annual Precipitation from 1960 to 2013



<u>Bounding Values for 1995 to 2002 Intrusion Rate</u> – The bounding values for the 1995 to 2002 tank T-111 intrusion rate are dependent upon evaporation rate and the minimum and maximum values for the leak rate.

Averaging all the calculated tank T-111 level change data points from July 1995 to January 2002 in Figure 11 gives an average tank T-111 level change rate of 0.166 in./yr. This is equivalent to a volumetric change rate of 486 × 0.166 = 80.6 gal/yr from July 1995 to January 2002. Using the equation:

$$Intrusion\ Rate = Net\ Change\ Rate + Evaporation\ Rate + Leak\ Rate$$

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 gal/yr + evaporation rate + leak rate

The minimum leak rate from tank T-111 from 1995 to 2002 was zero. For the minimum to be zero the intrusion rate would range from 80.6 to 273.6 gal/yr depending upon the rate of evaporation from the tank. This is determined as follows:

If the tank T-111 breathing rate is zero the evaporation rate is zero. With the leak rate zero:

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 + 0 + 0 = 80.6 gal/yr

If the tank T-111 breathing rate is the 2.4 cfm previously estimated the evaporation rate is 63 gal/yr. With the leak rate zero:

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 + 63 + 0 = 143.6 gal/yr

If the tank T-111 breathing rate is the 6.0 cfm previously estimated the evaporation rate is 193 gal/yr. With the leak rate zero:

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 + 193 + 0 = 273.6 gal/yr

The maximum leak rate from tank T-111 from 1995 to 2002 is assumed a nominal 100 gal/yr. For the maximum to be 100 gal/yr the intrusion rate would range from 180.6 to 373.6 gal/yr depending upon the rate of evaporation from the tank. This is determined as follows:

Using the same formula above:

$$Intrusion\ Rate = Net\ Change\ Rate + Evaporation\ Rate + Leak\ Rate$$

If the tank T-111 breathing rate is zero the evaporation rate is zero. With the leak rate 100 gal/yr:

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 + 0 + 100 = 180.6 gal/yr

If the tank T-111 breathing rate is the 2.4 cfm previously estimated the evaporation rate is 63 gal/yr. With the leak rate 100 gal/yr:

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 + 63 + 100 = 243.6 gal/yr

If the tank T-111 breathing rate is the 6.0 cfm previously estimated the evaporation rate is 193 gal/yr. With the leak rate 100 gal/yr:

Tank T-111 July 1995 to January 2002 intrusion rate = 80.6 + 193 + 100 = 373.6 gal/yr

The range of intrusion rates that would result in a maximum tank T-111 leak rate of 100 gal/yr during the 1995 to 2002 period is supported by intrusion observations in other tanks. Intrusion rates seen in 2012 and 2013 for BX-BY tank farm 75 ft. diameter tanks have ranged from roughly 80-400 gal/yr. A rate of about 400 gal/yr has also been observed in tank 241-SX-106 (SX-106). Intrusion causes in these BX/BY tanks and tank SX-106 are believed to be more significant than for a T-Farm SST based upon potential contributing causes. All of the tanks are susceptible to intrusion from cracks or unsealed openings, but in addition the BX/BY tanks are subject to intrusion drainage from an extensive system of subsurface encasements not present in T-Farm, and tank SX-106 has the low collection point for the subsurface ventilation system ducting connecting all 15 SX-Farm tanks. Active intrusions have been seen in the BX/BY tanks coming from pit drains connected to the encasement system and an active intrusion has been seen coming from the SX ventilation header draining into SX-106. It is highly unlikely that any intrusion into tank T-111 would be greater than into the BX/BY tanks or tank SX-106, so the nominal 180 to 375 gal/yr intrusion rates calculated for tank T-111 with a 100 gal/yr leak rate out of the tank are conservative. Thus, assuming a maximum 100 gal/yr leak rate from 1995 to 2002 is conservative.

5.0 Estimation of a Tank T-111 Volumetric Leak Rate and Leak Volume

The tank T-111 leak rate is calculated by:

$$Leak\ Rate = Intrusion\ Rate - Evaporation\ Rate - Net\ Change\ Rate$$

where both evaporation and leak rates are expressed as positive values.

There are four leak rate scenarios consistent with the data in Figures 1 and 11:

A. The leak began when the magnitude of the tank level change rate slope began to decrease in 2002. The intrusion into tank T-111 remained constant from 1995 to October 2007, when the intrusion began to decrease following grading in T Farm.
B. The leak began when the magnitude of the tank level change rate slope began to decrease in 2002. The intrusion into tank T-111 has remained constant since 1995.
C. The leak began sometime after intrusion into tank T-111 began to decrease in early 2002.
D. The leak began before 1995. In 2002 either the intrusion began to slow down, the leak began to increase, or changes to both occurred which resulted in a decrease in the net change rate.

A tank T-111 leak rate will be estimated for a number of different scenarios consistent with these postulated leak scenarios. The scenarios vary with evaporation rate assumptions, intrusion rate change assumptions, and assumptions as to whether the decrease in the net change rate is due to the intrusion rate decreasing, the leak rate increasing, or both. All the assumed scenarios are described in Appendix A. The most probable leak rate scenario assumes the tank T-111 1995 to 2002 leak rate was zero. This scenario is described below.

It is assumed for this document that the most probable post-1994 leak scenario for tank T-111 is:

- The tank had a negligible leak rate from 1995 until early 2002, at which time it began to leak slowly but at an increasing rate.
- The tank intrusion rate remained constant at 143.6 gal/yr (includes 63 gal/yr to offset evaporation) from July 1995 to April 2013, with no decrease.

This scenario is based upon:

- If the tank level change rate is constant, which it was from 1995 to 2002, then the intrusion rate minus the evaporation rate minus the leak rate is constant. It is reasonable to assume the evaporation rate will be constant on an annual basis providing there is negligible change to the tank breathing rate and the degree of moisture on the waste surface. It is also reasonable to assume that intrusion will remain constant on an annual basis unless actions are taken that will impact the intrusion rate. Tank leak rates, while they may not change much on a daily basis will usually not stay the same on an annual basis. It is unlikely that all three factors will remain constant over a period of 7 years.
- From Figures 19 and 10 it is apparent that the net change rate from 1979 to 1989 remained essentially constant at about the same net change rate from 1995 to 2002. It is unlikely that there would be two post-interim stabilization pumping periods where all three factors were in balance with each other, at about the same net change rate, for a long period of time.
- With the liquid pool in the center of the tank, the waste surface being moist, and the waste level being within 3-4 feet of the top of the liner it is reasonable to assume there is evaporation occurring.

The estimated tank T-111 leak rate for the most likely scenario was calculated using the above intrusion rate and evaporation assumptions and the Figure 11 level change rates. Figure 14 provides the estimated leak rate. The leak rate as of April 1, 2013 calculates to about 2.8 gal/day.

The daily leak volume is equal to the daily leak rate for one day. Figure 15 plots the cumulative leak volume. The estimated post-1994 leak volume for tank T-111 was calculated by adding up the daily leak volumes >0.05 gal. The 0.05 gal value is used as a cutoff to minimize small, mathematically existent but empirically non-existent variations caused by using the polynomial trendline for the level change data. A leak rate of 0.05 gal/day is less than 20 gal/yr and of negligible impact in calculating a total leak volume for tank T-111. The tank T-111 post-1994 leak volume as of April 1, 2013 is estimated at about 2,100 gal.

This 2,100 gal estimate is based upon the 1995 to 2002 leak rate from tank T-111 being zero. This is believed to be the most realistic assumption based on tank leak experience where leak rates seldom remained constant for an extended period of time, and the likelihood of the intrusion rate and the leak rate exactly balancing each other for an extended period of time is even lower. This document evaluates as an alternative a 100 gal/yr leak rate from 1995 to 2002 to give an upper limit to a tank T-111 leak volume.

Appendix A evaluates leak rates and post-1994 leak volumes assuming a 100 gal/yr leak from tank T-111 in 1995 to 2002, as well as a number of different scenarios with different intrusion rate decrease assumptions. For some scenarios a significant reduction in the intrusion rate results in an unrealistic change to the tank leak rate, i.e., it increases, then decreases, and then increases again. To illustrate this, consider again the Net Change Rate equation:

$$Net\ Change\ Rate = Intrusion\ Rate - Evaporation\ Rate - Leak\ Rate$$

where both evaporation and leak rates are expressed as positive values.

A stepwise decrease in the intrusion rate would require an equivalent stepwise change in the Net Change Rate, yet Figure 11 shows that the Net Change Rate curve is smooth and continuous. The intrusion rate may have moderately decreased following 2007, but not allowing for such a decrease does not significantly impact the final results.

There is no single definable number that can be stated for either the leak rate or leak volume. The range of scenarios in Appendix A reasonably bounds the leak rate as of April 1, 2013 between 2.0 and 3.1 gal/day, with the most likely rate 2.8 gal/day. The range of scenarios in Appendix A reasonably bounds the post-1994 leak volume as of April 1, 2013 between 1,000 and 3,900 gal, with the most likely post-1994 leak volume 2,100 gal.

Figure 14 Tank T-111 Estimated Leak Rate from 1995 to 2013

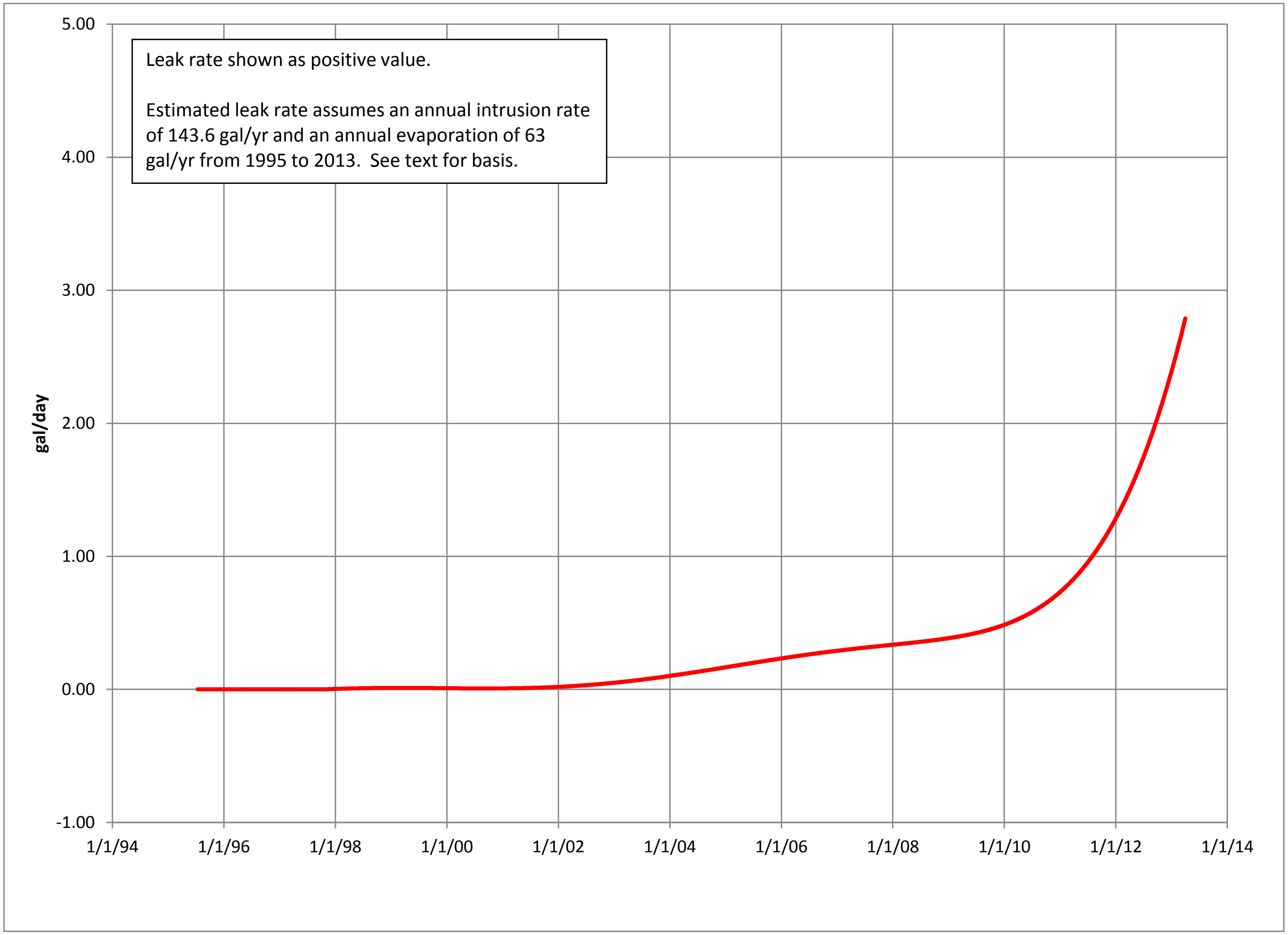
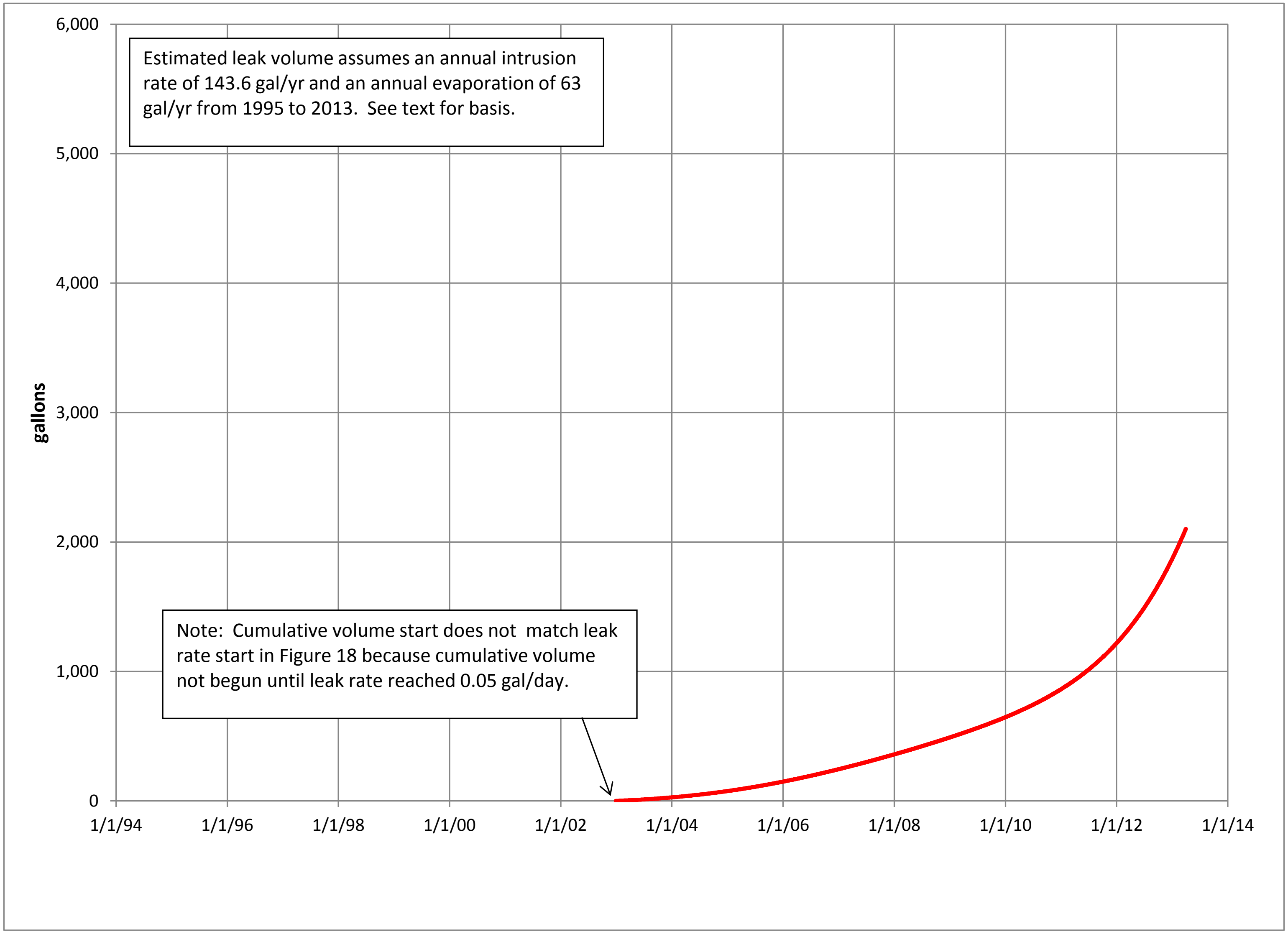


Figure 15 Tank T-111 Estimated Cumulative Leak Volume from 1995 to 2013



6.0 Additional Work

External Tank Drywell Radiation and Moisture Logging - Periodic drywell logging has been carried out in the past to attempt to find tank leaks and/or track the waste plume from known leaking tanks. Either moisture logging or gamma logging has been done to look for leaks while plume tracking is usually done with gamma logging. There are nine drywells located around tank T-111, eight of these are 4-in. pipe inside a 6-in. pipe, with grout in the annulus between the two. The ninth drywell is a 6-in. pipe. The presence of the grout renders moisture logging ineffective for tank T-111, only gamma logging would potentially be useful. The low radiation level of the liquid in tank T-111 (estimated at ~1.4 µCi/mL ^{137}Cs if all 195 Ci ^{137}Cs in the tank per the BBI was located in the 38,000 gal of drainable interstitial liquid calculated to be in the tank) results in the Radionuclide Assessment System (RAS) truck being of little benefit for tracking a tank T-111 leak, the more sensitive Spectral Gamma system would be necessary to obtain useful gamma scans.

Baseline spectral gamma scans of drywells around tank T-111 were obtained in 1998 along with other T-Farm drywells. Selected drywells were relogged with the spectral gamma system in 2008-2009 following installation of the T-Farm barrier (RPP-RPT-44202, *Hanford Geophysical Logging Project Spectral Gamma Re-Baseline Logging for the T-Farm Interim Surface Barrier*, Rev 0). Only two of the relogged drywells, 50-08-07 and 50-08-19, are near tank T-111, and adjacent to each other. This relogging showed minor movement of ^{60}Co 83 ft. Below Grade Surface (BGS) in 50-08-07 and possibly very minor movement of ^{60}Co 80 ft. BGS in 50-08-19 when compared to the 1998 scans. No change was detected in ^{137}Cs movement compared to the 1998 scans.

While obtaining spectral gamma scans for all the drywells around tank T-111 could provide updated information, it is doubtful that the added information would facilitate informed decisions concerning what to do with the tank contents. The limited contamination seen in the 1998 spectral gamma scans for the drywells around tank T-111 from post-1974 tank T-111 leaks, the relatively small size of the post-1994 leak, and the low concentration of gamma emitting radionuclides in the leak solution would contribute to the likely limited utility of additional spectral gamma data to track any tank T-111 leak. In addition, information from past geophysical scan documentation indicates at least three of the drywells around tank T-111 contain water, several of them up to near grade. This water should be removed prior to performing gamma scans.

Additional In-Tank Inspection Videos - The in-tank videos obtained on February 11 and March 20, 2013 were taken from Riser 6 and did not have good resolution of objects far away, such as the anomaly shown in Figure 6. It is desirable that the nature of this anomaly be understood to determine if it is an intrusion location or of structural interest. An in-tank video could be obtained from Riser 2, which is on the opposite side of the tank from Riser 6. Riser 2 is about equal distance from the anomaly as Riser 6, but the view would be from a different angle and a different camera would be used. If additional information about tank T-111 is needed to make an informed decision about the tank's intrusion status or structural integrity, then an in-tank video from Riser 2 is recommended.

7.0 Conclusions and Recommendations

The conclusions from this document (including Appendix A) are:

1. Tank T-111 is leaking.
2. The tank T-111 leak rate as of April 1, 2013 is between 2.0 and 3.1 gal/day, with the most likely rate about 2.8 gal/day.
3. The post-1994 tank T-111 leak volume is between 1,000 to 3,900 gal, with the most likely volume about 2,100 gal.
4. The intrusion rate into tank T-111 either did not decrease following the grading in T-Farm for installation of the interim surface barrier in 2007 or decreased at a moderate rate to near zero over a five to six year period.
5. The calculated intrusion rate is dependent upon the assumed evaporation rate. If there was no decrease in the intrusion rate from 1995 to 2013, then evaporation has no impact on the estimated leak volume. If the intrusion rate decreased then evaporation has an impact on the estimated leak volume, i.e., higher evaporation rates result in a decreased estimated leak volume.

The recommendations are:

1. Continue obtaining monthly LOW data for tank T-111 until the current negative trendline slope for the ILL data decreases, i.e., becomes less negative, and indicates an asymptotic change rate, then return to quarterly monitoring. The additional data may not alter any decisions to be made on actions to be taken but it is prudent that up to date data be available on what is going on in a tank that is leaking so new information and/or trends become readily apparent.
2. Continue daily Enraf gauge surface level monitoring.
3. Obtain a tank T-111 video from Riser 2 to permit viewing of the anomaly on the southeast side of the tank above the dome/stiffener ring interface from a different angle, and to observe the tank liner better on the opposite side of the tank from the video taken through Riser 6.
4. If direct evidence of a tank leak is needed that is not dependent upon assumptions related to the competing factors of intrusion, evaporation, or leakage another technology must be deployed that directly monitors leakage from the tank. There is little additional tank leak related information that can be obtained from existing data or monitoring techniques.

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Appendix A

Evaluation of Tank T-111 Potential Leak Scenarios

Figures 1 and 11 show the tank T-111 ILL and SL changes with time. Simplifying these plots there was a constant increasing level change from 1995 until around the start of 2002, at which time the increase rate began to slow. The level change reached zero around 2006 and began to decrease shortly after. The level change decrease rate has accelerated with time. In order to estimate a tank leak rate (and leak volume) the following need to be known or estimated:

- What is the waste porosity and fraction of the waste surface that is liquid (needed to convert an inches/year change rate to a gallons/year change rate)?
- What is the tank intrusion rate?
- What is the tank evaporation rate?
- Was the tank leaking in 1995?
- What caused the level change increase rate to slow in 2002? Did the intrusion rate slow down or did the leak begin or increase?
- Did the T-Farm barrier grading in 2007 decrease the intrusion rate?

There are too many variables and unknowns to accurately calculate a tank T-111 leak rate and post-1994 leak volume, but a leak rate and volume can be reasonably bounded by selecting conservative and non-conservative assumptions for the above questions to make different tank scenarios and evaluating the results.

Different assumptions were made for:

- Intrusion rate
- Onset date for intrusion rate decrease
- Intrusion decrease rate
- Evaporation rate
- Onset date of leak
- Leak rate at leak onset
- Leak rate change

Scenarios did not include different assumptions for waste porosity and fraction of the waste surface that is liquid, but the impact of these assumptions is addressed at the end of the appendix.

Table A-1 lists the scenarios and assumptions. Numerous other scenarios could be postulated, but the ones presented in the table are adequate to provide reasonably bounding estimates for the tank T-111 leak rate under different conditions.

The leak rate is calculated from:

$$Leak\ Rate = Intrusion\ Rate - Evaporation\ Rate - Net\ Change\ Rate\ from\ Figure\ 11$$

where evaporation, intrusion, and leak rate are all positive numbers.

An Excel file was built to provide the calculated leak rates and leak volumes for all scenarios. The file enables various evaporation rates, intrusion rates, waste porosities and waste liquid surface fractions to be used. Figures A-1 and A-2 plot the leak rate results and Figures A-3 and A-4 plot the leak volume results.

Table A-1 Tank T-111 Postulated Leak Scenarios

Scenario	Intrusion Rate[1] 7/15/95 (gal/yr)	Onset of Intrusion Rate Decrease	Evaporation Rate (gal/yr)	Intrusion Decrease Rate	Onset of Leak	Leak Rate at Onset (gal/yr)	Leak Rate Change
1ev	143.6 (80.6+63+0)	10/15/07	63	Immediately to zero	Calculated from intrusion minus evaporation minus level change	zero	As calculated
2ev	143.6 (80.6+63+0)	10/15/07	63	Linear rate to zero in 1 year	Calculated from intrusion minus evaporation minus level change	zero	As calculated
3ev	143.6 (80.6+63+0)	10/15/07	63	Linear rate to zero in 5 years	Calculated from intrusion minus evaporation minus level change	zero	As calculated
4ev	143.6 (80.6+63+0)	NA-constant	63	NA-constant	Calculated from intrusion minus evaporation minus level change	zero	As calculated
5ev	143.6 (80.6+63+0)	10/15/07	63	All level change from 10/15/07 due to intrusion decrease	Calculated from intrusion minus evaporation minus level change	zero	As calculated to 10/15/07, constant until intrusion zero, then as calculated
6ev	143.6 (80.6+63+0)	01/01/02	63	All level change from 01/01/02 due to intrusion decrease	Calculated from intrusion minus evaporation minus level change	zero	As calculated
7ev	243.6 (80.6+63+100)	NA-constant	63	NA-constant	Calculated from intrusion minus evaporation minus level change	100[2]	As calculated
8ev	273.6 (80.6+193+0)	10/15/07	193	Linear rate to zero in 5 years	Calculated from intrusion minus evaporation minus level change	zero	As calculated

Table A-1 Tank T-111 Postulated Leak Scenarios

Scenario	Intrusion Rate[1] 7/15/95 (gal/yr)	Onset of Intrusion Rate Decrease	Evaporation Rate (gal/yr)	Intrusion Decrease Rate	Onset of Leak	Leak Rate at Onset (gal/yr)	Leak Rate Change
1nev	80.6 (80.6+0+0)	10/15/07	0	Immediately to zero	Calculated from intrusion minus evaporation minus level change	zero	As calculated
2nev	80.6 (80.6+0+0)	10/15/07	0	Linear rate to zero in 1 year	Calculated from intrusion minus evaporation minus level change	zero	As calculated
3nev	80.6 (80.6+0+0)	10/15/07	0	Linear rate to zero in 5 years	Calculated from intrusion minus evaporation minus level change	zero	As calculated
4nev	80.6 (80.6+0+0)	NA-constant	0	NA-constant	Calculated from intrusion minus evaporation minus level change	zero	As calculated
5nev	80.6 (80.6+0+0)	10/15/07	0	All level change from 10/15/07 due to intrusion decrease	Calculated from intrusion minus evaporation minus level change	zero	As calculated to 10/15/07, constant until intrusion zero, then as calculated
6nev	80.6 (80.6+0+0)	01/01/02	0	All level change from 01/01/02 due to intrusion decrease	Calculated from intrusion minus evaporation minus level change	zero	As calculated
7nev	180.6 (80.6+0+100)	NA-constant	0	NA-constant	Calculated from intrusion minus evaporation minus level change	100[2]	As calculated

Table Notes:

1. $Intrusion\ Rate = Net\ Change\ Rate + Evaporation\ Rate + Leak\ Rate$ (where evaporation and leak rates are positive)
2. 100 gal/yr selected for 1995 leak rate as a conservative example. See main body of document for basis.

Figure A-1 Tank T-111 Estimated Post-1994 Leak Rate Scenarios with Evaporation

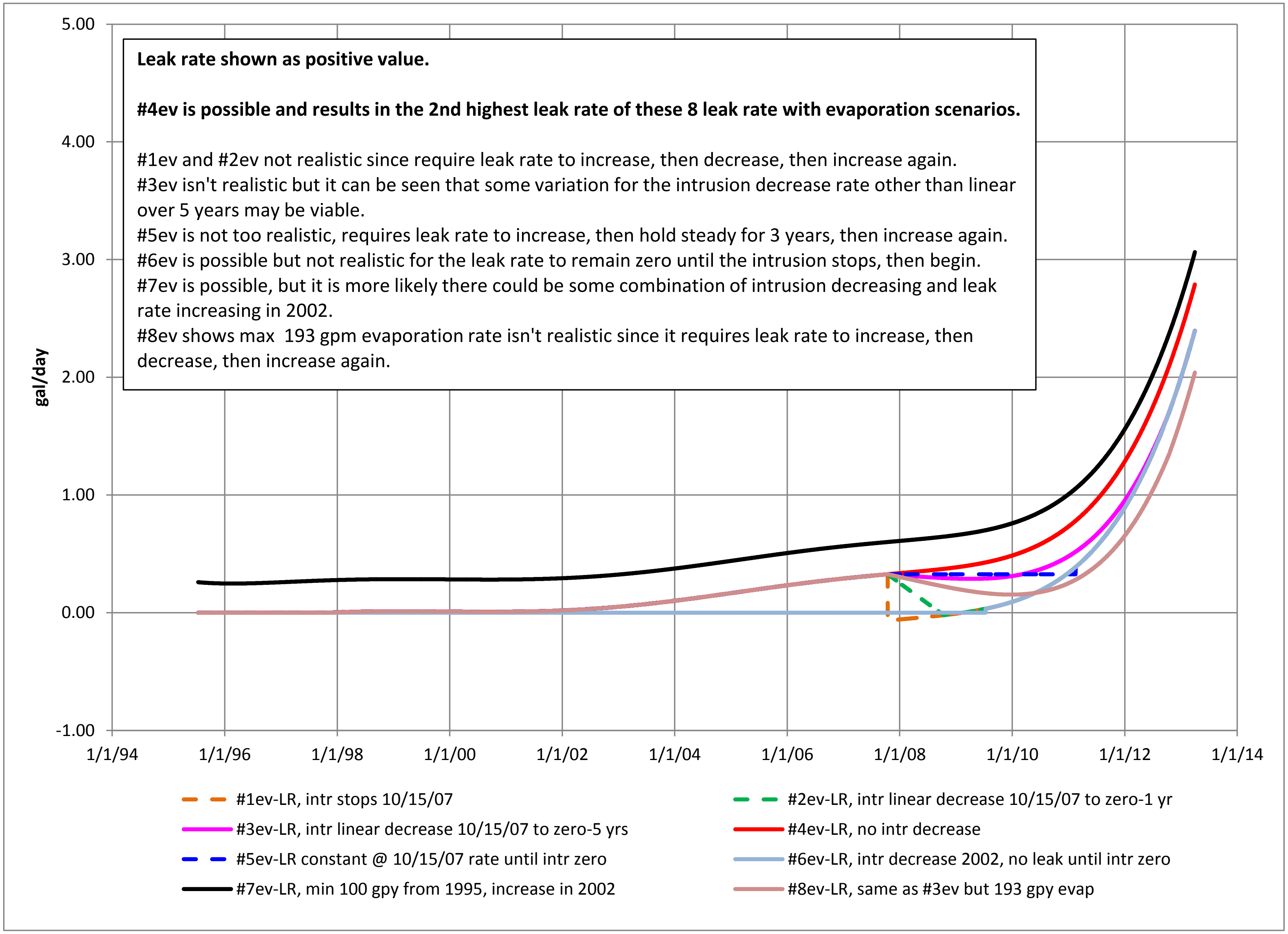


Figure A-2 Tank T-111 Estimated Post-1994 Leak Rate Scenarios without Evaporation

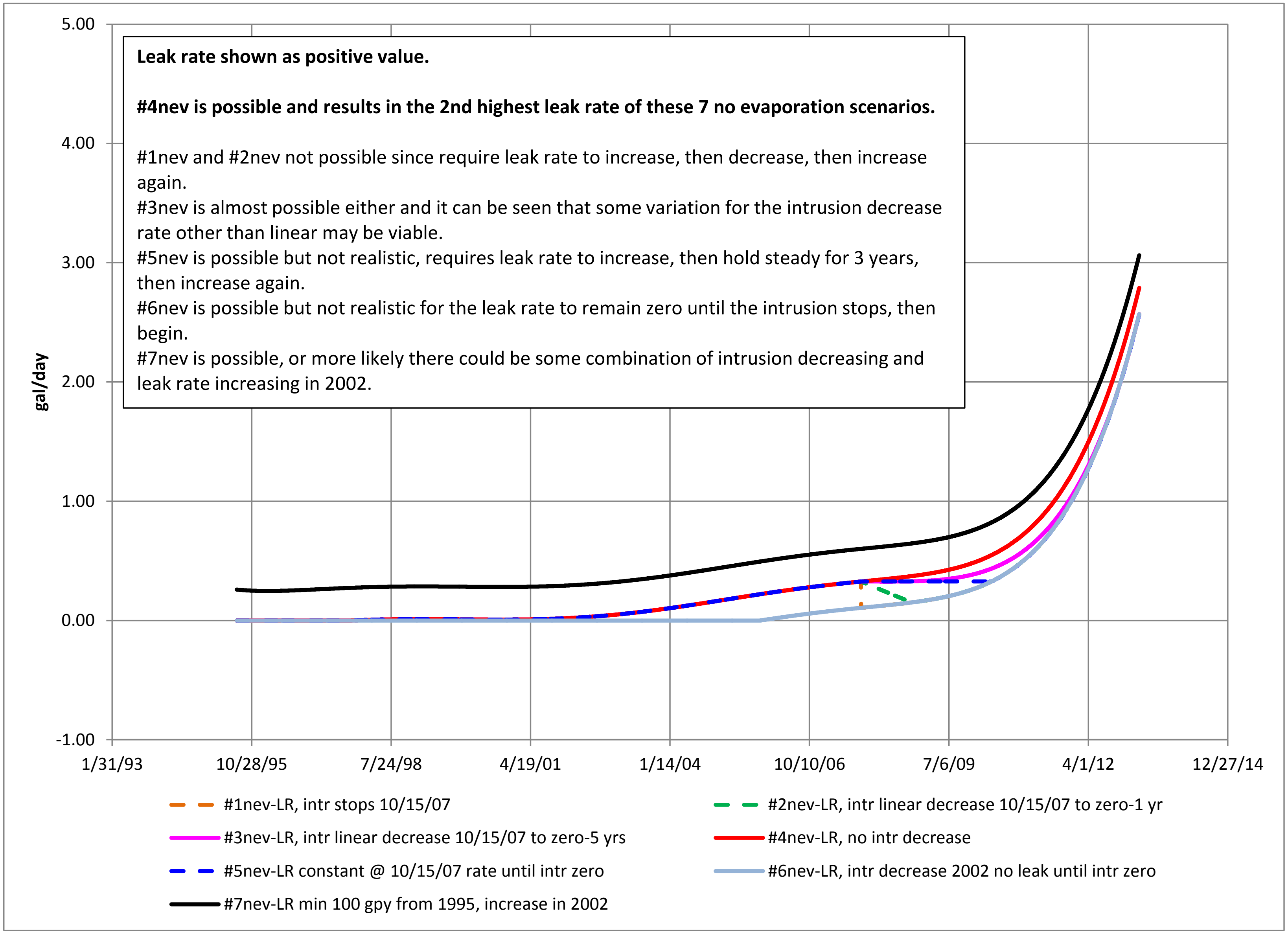


Figure A-3 Tank T-111 Estimated Post-1994 Leak Volume Scenarios with Evaporation

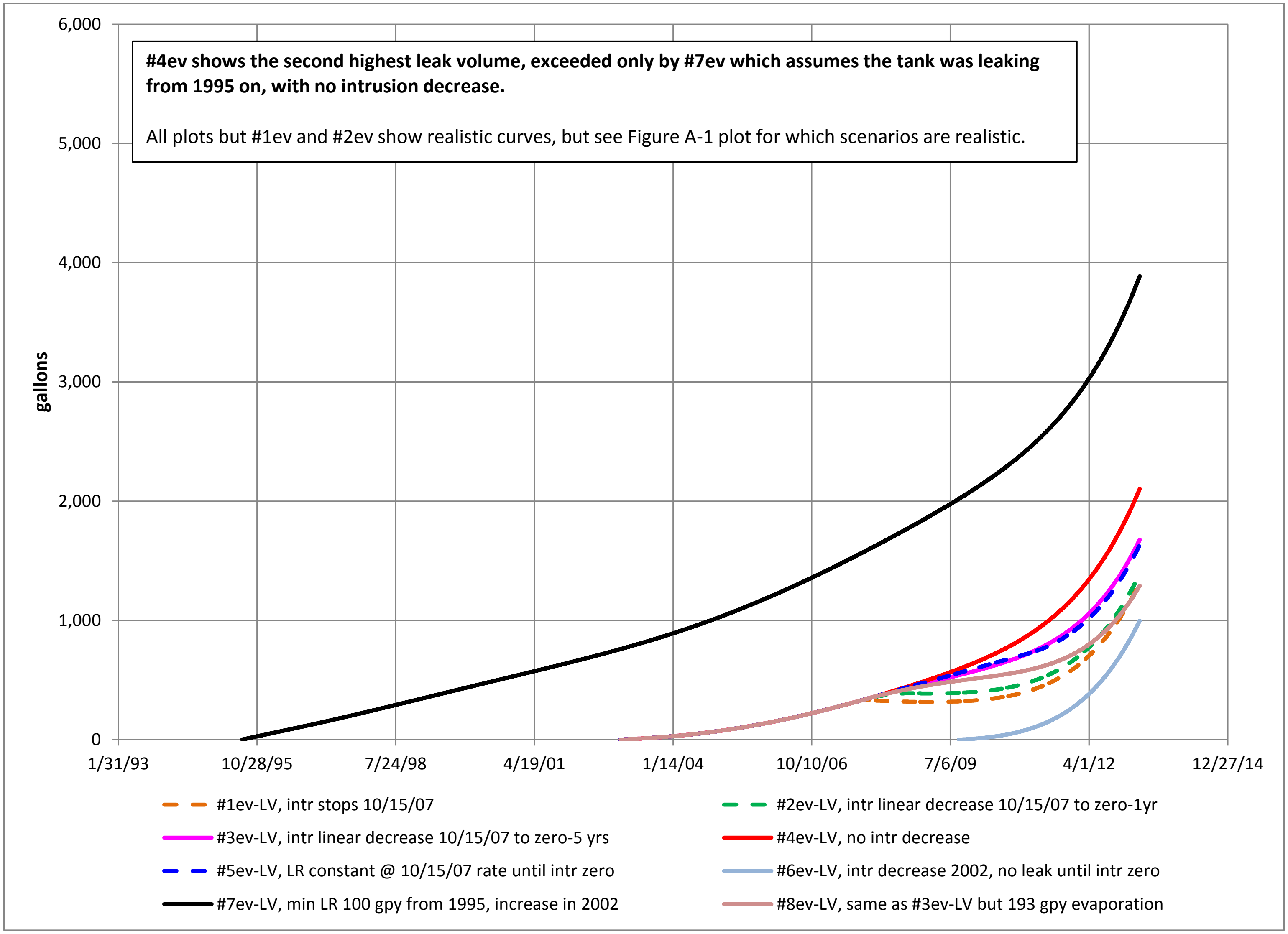
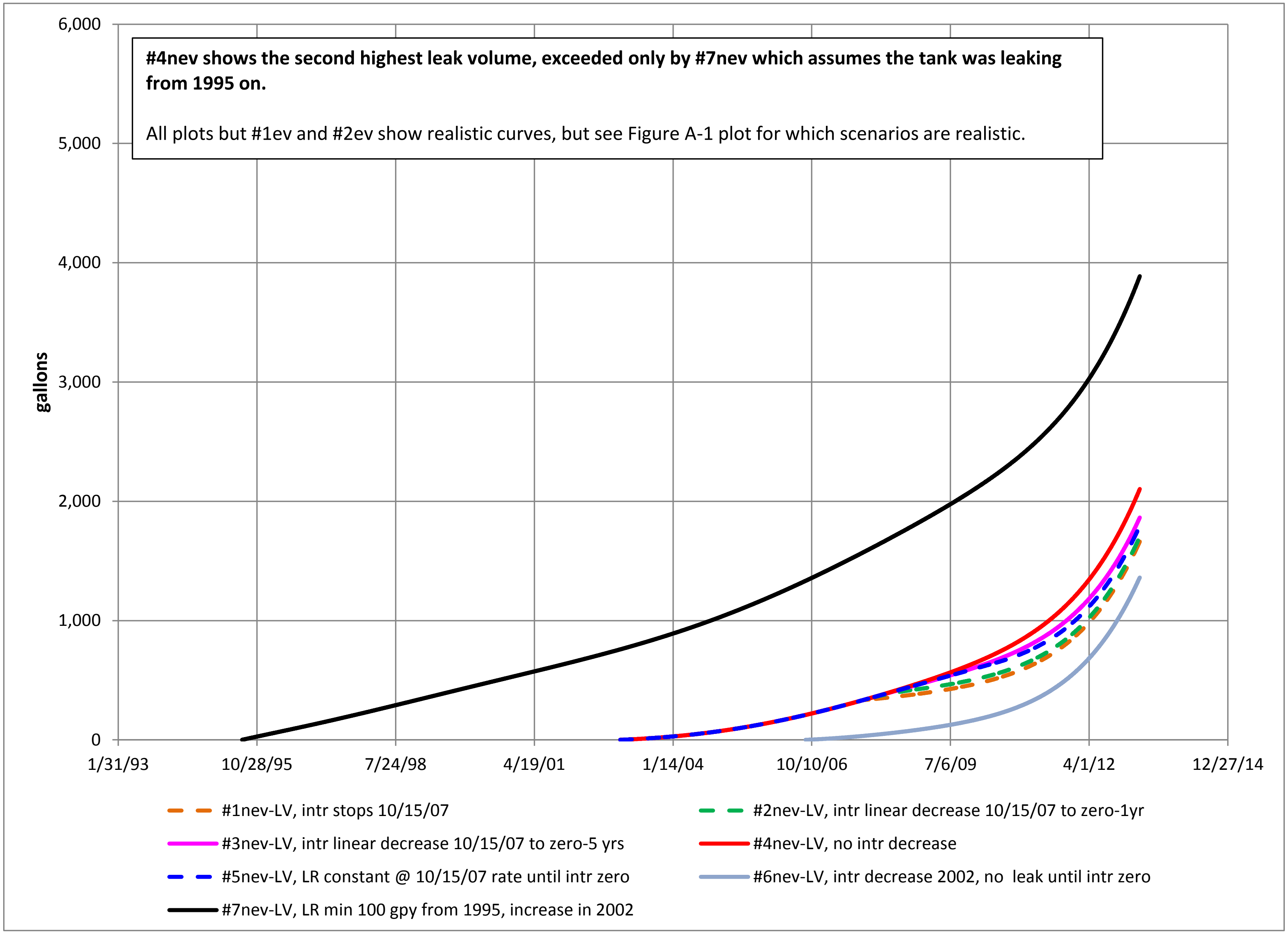


Figure A-4 Tank T-111 Estimated Post-1994 Leak Volume Scenarios without Evaporation



From Figures A-1 and A-2 it is apparent, if the assumptions for waste porosity and waste liquid surface fraction are adequate, that the intrusion into tank T-111 did not stop or slow down much after October 2007 when the grading began in T-Farm. Even if the intrusion rate went to zero (linearly) over 5 years the plot shows an unlikely drop in the leak rate before rising again when accounting for evaporation. However, with alterations to the decrease rate scenarios 3ev and 3nev would be viable.

The scenario plots which show the most realistic change for the leak rate when accounting for evaporation are for when there is no intrusion rate change. The plot for when the intrusion decrease begins early in 2002 is also realistic looking but it seems improbable that the leak rate was zero until the intrusion stopped, then the leak started. A combination of the intrusion decrease and leak beginning sometime after early 2002 is probable; regardless of the actual conditions this scenario results in a lower leak rate than if there were no intrusion rate reduction.

The main information to take from Figures A-1 and A-2, if the assumptions for waste porosity and waste liquid surface fraction are adequate, is:

- Tank T-111 probably began to leak somewhere between 2002 and 2009, most likely around 2002
- Tank T-111 could have been leaking from 1995 on, but it doesn't seem realistic for the leak rate to be constant for many years and then begin a significant increase
- The tank T-111 leak rate as of April 1, 2013 is between 2.0 and 3.1 gal/day

Besides Figures 14 and 15, there are many other scenarios that could be evaluated. The main information to take from Figures A-3 and A-4, if the assumptions for waste porosity and waste liquid surface fraction are adequate, is:

- The post-1994 tank T-111 leak volume is probably between 1,000 to 3,900 gal, with the most likely volume about 2,100 gal. The volume would be in the 3,900 gal range only if the tank were leaking at a minimum 100 gal/yr from 1995 on, the intrusion remained constant, and the leak rate began to increase when the level change rate began to decrease.

Figures A-1 to A-4 are based upon the assumptions that the fraction of waste surface that is liquid is constant at 0.08 and the waste porosity is constant at 0.105. While the basis for both of these assumptions is explained in Section 4.0, postulated different values could also explain the shape of the ILL and SL data plots in Figure 11.

One alternate explanation for the shape of the plots in Figure 9 is that there was no decrease in the intrusion rate nor did the tank begin to leak around 2002, instead the intrusion rate only appeared to decrease because the central pool diameter was expanding as the liquid level rose. This would result from the liquid coming out of the depression around the saltwell screen and as the diameter expands there is less of an increase in height for the same volume, so it looks like the level change rate is different when the net liquid in and out of the tank is not changing.

While the cross-sectional area of the central pool likely did change, it is not believed to have changed much based. Figure A-5 is a photo of the central pool area on April 13, 1994 when the SL was 173.1 in. and the ILL was 169.3 in. This was about a month before saltwell jet pumping began. Figure A-6 is a screenshot of the same area from the video obtained on March 20, 2013 when the SL was 167.6 in. and the ILL was 164.4 in. The white stripe on the saltwell screen is about 4 inches lower in the 2013 image. When the intrusion begins to be noticed in the SL trace in Figure 9 in 1995 the SL is about 169 in., or about halfway between the 1994 and 2013 images. From Figure A-5 the liquid level can be observed out to where the surface is almost flat. In Figure A-6 it is not practical to see where the liquid level is with respect to the outer edge of the depression area. It is possible that it is near where the pool begins to get darker a few feet in from the outer edge. Regardless, the diameter of the liquid pool does not appear to be significantly different between April 1994 and March 2013, so the fraction of the waste surface that was liquid did not change much between 1995 and 2013.

A second alternate explanation for the shape of the traces in Figure 9 is that the waste is more porous near the surface because of less weight packing the material down, and that the porosity decreases with waste depth. If the porosity decreases with waste depth (and increases as the ILL gets near the surface) then the intrusion rate will again appear to decrease as the liquid level rises and the leakage or evaporation rate appear to increase as the liquid level decreases. It is indeed likely that the porosity is higher close to the surface, but there is no basis for using a formula for waste porosity that is a function of waste depth, especially when the depth change is only a few inches over 18 years (1995 to 2013). Using the value of 0.105 derived from interim stabilization performance is considered appropriate for the analysis. Using a different value would result in a different value for the post-1994 leak volume, but the volume difference would not be significant and will not alter the conclusion that the tank is leaking at this time.

Figure A-5 Tank T-111 Central Pool on April 13, 1994

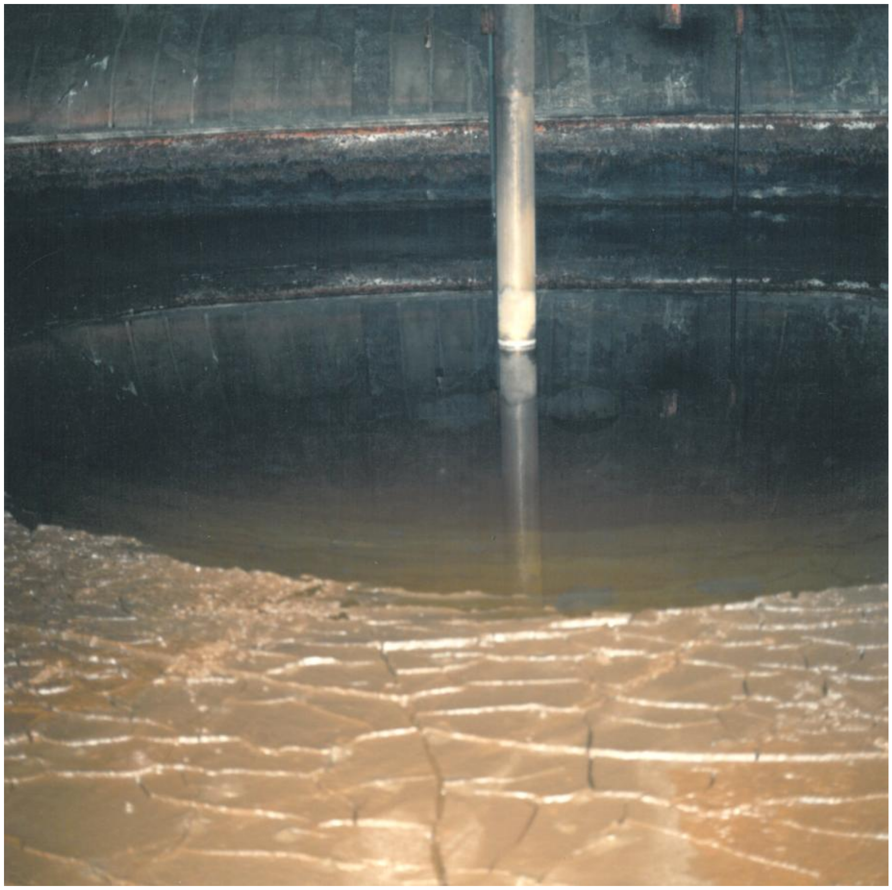


Figure A-6 Tank T-111 Central Pool on March 20, 2013